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GLAUCOPHANE SCHISTS AND ECLOGITES NEAR HEALDSBURG, CALIFORNIA

BY IRIS Y. BORG

ABSTRACT

Glaucophane schists, hornblende rocks, and eclogites are intimately associated within the Franciscan formation of the Healdsburg quadrangle. Discontinuity of megascopic structures and rapid variation in rock type indicate that the schists have undergone considerable disturbance since formation. However, weak trends conforming to the regional structure of the Franciscan formation can still be discerned in the metamorphic rocks. Most of the metamorphic rocks are derived from basic igneous rocks. The parents of the pumpellyite-lawsonite-glaucophane schists are dense aphanitic volcanic rocks termed greenstones. The quartz-rich rocks show close chemical affinities with Franciscan cherts and arkosic wackes.

Eclogites bearing almandite garnet and acmitic diopside-jadeite are mineralogically atypical with reference to eclogites found elsewhere. It would seem that at one time they were more extensively developed in the area, for several existing rock types appear to have formed from them by retrograde processes. Retrograde products are members of the albite-epidote-amphibolite, greenschist, and glaucophane schist facies. Some members of the first two groups have been subsequently modified by the crystallization of glaucophane. Final products in such rocks are chlorite-glaucophane schists with remnant hornblende, and muscovite-chlorite-glaucophane schists with remnant pyroxene. Conditions accompanying the development of the eclogite are unknown.

Although serpentinite is associated with the group, the genesis of the schists and eclogite appears to be unrelated to it. The similarity in chemical composition between the schists and unaltered basaltic rocks and sediments of the formation suggests that the metamorphism was not accompanied by metasomatism.

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Introduction

In the past 5 years there has been an increased interest in glaucophane schists and the petrogenetic problems they pose. The glaucophane schists of the California Coast Ranges are particularly perplexing because of their sporadic occurrence within an otherwise unmetamorphosed geosynclinal suite, the Franciscan formation (Taliaferro, 1943; Reed, 1933). The arkosic and lithic wackes, shales, cherts, and basic igneous rocks constituting the bulk of the formation rarely grade into the schists. Commonly areas containing metamorphic rocks are a few hundred feet in dimension and are surrounded by unaltered sediments. Serpentinized peridotite is rarely far distant.

The purpose of this investigation is to supply data concerning field, petrographic, mineralogical, and chemical relations in one typical area. The area chosen is within a belt of glaucophane schists occurring in the Healdsburg quadrangle, 65 miles northwest of San Francisco. A sketch map of the area surrounding the largest series of continuous outcrops of the metamorphic rocks in the quadrangle is shown in Figure 1.

References to rocks found within the Healdsburg quadrangle may be found in almost every account of the glaucophane schists in California. The first discussion of the Healdsburg localities is that of Nutter and Barber (1902). The most important work in the region was done by Gealey (1951), who mapped the quadrangle, and by Switzer, who described the mineralogy of the schists (Switzer, 1951) and the associated eclogites (Switzer, 1945).

Acknowledgments

The writer is particularly indebted to Dr. F. J. Turner under whose direction the project was undertaken, for profitable discussions and for critically reading the manuscript. Drs. A. Pabst, C. M. Gilbert, and L. Weiss also contributed valuable comment and technical aid. The work was made possible by a Genevieve McElenery Fellowship. The Department of Geology of the University of California generously paid for all but one analysis.

Distribution of Rock Types

The area studied surrounds the Junction School and is characterized by low relief. Outcrops of metamorphic rocks, usually less than 20 feet in diameter, dot the countryside. At no place within the area are schists continously exposed, nor do they grade into Franciscan sediments and igneous rocks. Except for the serpentinite body, it is not possible to map boundaries of rock types. Rapid change in lithology and orientation of megascopic structural features indicate that many of the outcrops do not reflect the mineralogy or attitude of underlying rock. The outcrop map (Fig. 2) shows the distribution of five rock types:

(1) Serpentinite, in places somewhat sheared, forms a continuous belt trending N. 60°–70° W. in general conformity with the foliation of the adjacent schists and with the regional structure (Cf. Fig. 1). In part the serpentinite flanks a topographic depression along which Gealey mapped a fault. There are also scattered, isolated outcrops of serpentinite not visibly related to the main mass.

(2) Strongly lineated lawsonite-glaucophane-quartz schist veined with quartz is the most extensively developed metamorphic rock. It is confined to the northern and northeastern sectors of the area.

(3) Greenstone is also plentiful although not limited to any one part of the area. It is concen-

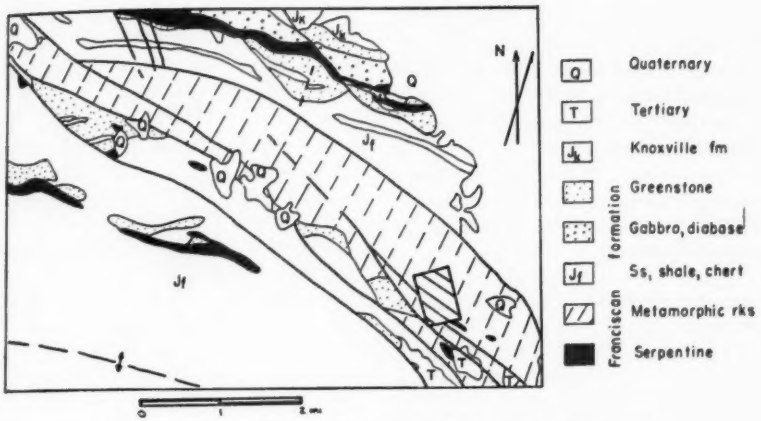

FIGURE 1.—SKETCH MAP OF PORTION OF HEALSDBURG QUADRANGLE
Showing location of area investigated (modified from Gealey, 1951)

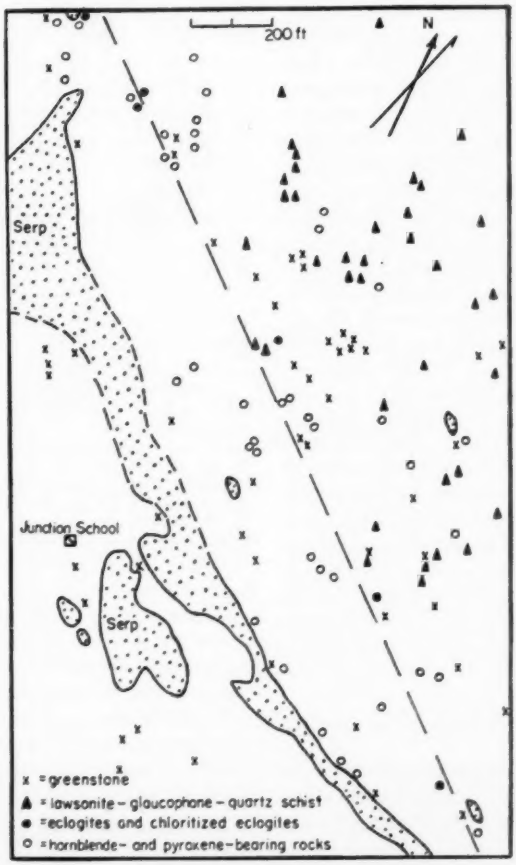

FIGURE 2.—AREAL DISTRIBUTION OF ROCK TYPES

trated in two belts that trend N. 60°–70° W. Outcrops within the westernmost belt are adjacent to and on both sides of the serpentinite body. Within this belt most outcrops are greenstone in contrast to the eastern belt which contains other rock types as well.

(4) Eclogite occurs in six outcrops nearly aligned along a line trending N. 50° W. (broken line of Fig. 2) subparallel to and east of the main serpentinite body.

(5) Outcrops of hornblende and pyroxene rocks with and without garnet are closely associated with the eclogite and similarly aligned, though not so narrowly limited in distribution. They are related to the eclogite by diaphthoritic processes.

Two contrasting elements emerge from the structural picture afforded by the outcrop map. Superficially there is general impression of chaos resulting from wide petrographic variety of rocks exposed and rapid variation between adjacent outcrops. Nevertheless, the main rock types tend to outcrop predominantly in limited belts whose N. 60°–70° W. trend is parallel to that of the regional structure. In spite of the capricious nature of the metamorphic rocks, the effects of subsequent structural disturbance, and the probability that many of the rock masses have migrated from their initial positions during development of the present topography, a kind of ghost stratigraphy survives.

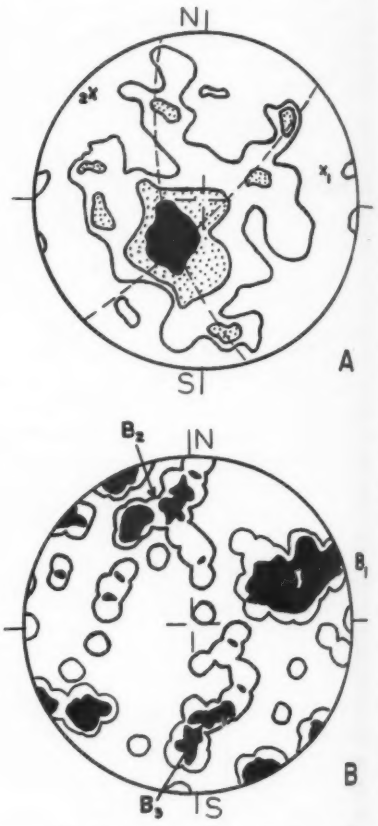

FIGURE 3.—EQUAL-AREA PROJECTION OF POLES OF FOLIATION AND LINEATION

a. 184 poles of foliation; contours 0–1–2–3 per cent, maximum 6 per cent. Maximum concentration corresponds to planes N. 55° W., 25° NE. Dashed lines trace girdles whose poles, X_1 and X_2, are N. 75° E., 25° NE. and N. 45° W., 10° NW., respectively (lower hemisphere). b. 72 lineations; contours 0–1.4–2.8 per cent, maximum 4 per cent. B_1, B_2, and B_3 are maxima having the following trends respectively: N. 75° E., 25° NE.; N. 20° W., 20° NW.; NS., 35° S. (lower hemisphere)

STRUCTURE

Description of Exposures

About half of the 590 outcrops visited are not in place or contain no measurable structure. Among the schists two types of outcrop occur, a rounded variety devoid of all structure except irregular banding and an angular type consisting of blocks of schist with well-developed planar and linear structure. Rocks of the first category contain abundant hornblende and/or pyroxene, and in places glaucophane replaces pre-existing amphiboles.

Statistical Analysis of Schistosity and Lineation

Following the methods developed during the last two decades by the Innsbruck school (Sander, 1930; 1950), a statistical analysis of structural data has been made by transferring the attitudes of schistosity, lineation, and fold axes to equal-area projections (Fig.3, A and B). The data may be summarized as follows:

(1) The degree to which structural elements such as schistosity and lineation are developed is highly variable; nonetheless the rocks show a moderate degree of regularity in their attitude.

(2) The schistosity of the schists trends

N. 55° W. and dips 25° NE. thereby paralleling the regional structural trend (N. 50°–65° W.) and the strike of the bedding in the adjacent areas of unaltered Franciscan sedimentary rocks.

(3) Folding is statistically determined to have taken place about an axis trending N. 75° E. and plunging 25° NE. Lineations (B_1, Fig. 3, B) parallel the fold axis. A second weaker fold axis is indicated by the intersection of s planes (β) and by a tendency of poles to s planes to form a girdle about an axis trending N. 45° W. and plunging 10° NW., (X_2 of Fig. 3, A). A statistical concentration of lineations (B_2 of Fig. 3, B) occurs 30° from the axis of the girdle, but its development could not be positively related to the folding.

Gealey recognizes two periods of major folding and faulting occurring in the middle-Eocene to middle-Miocene and Pliocene to Pleistocene times, respectively. The first diastrophism, considered by Gealey to be more important, involved folding about an axis trending N. 70° W. and does not appear to have expression in the small area considered. A weak fold axis trending N. 45° W. and plunging 10° NW. described here may or may not reflect the second deformation, since the Pliocene-Pleistocene folding is believed by Gealey to have been about an axis with this trend. The most important folding in the area, about an axis N. 75° E., 25° NE. does not fit into this oversimplified picture. It is possible that these trends represent a Jurassic deformation concomitant with recrystallization.

Petrography

Group I.—Greenstones

The greenstones are dense, aphanitic rocks weathered to a dull brown color. They are found throughout the Franciscan formation, and in many areas it is possible to recognize their original mineral constituents and to demonstrate that they are altered basic and intermediate extrusive rocks. They vary from a fine-grained rock containing large amounts of partly altered augite (2V = (+) 52°, 66°; $c \wedge Z$ = 41°, 45°) to a completely altered volcanic rock in which large, ragged crystals of lawsonite containing abundant inclusions are imbedded in a matrix of fine-grained unidentified material. The only rocks in the area containing both lawsonite and epidote are greenstones traversed by veins of epidote and pumpellyite. The incompatibility of lawsonite and epidote has been commented on by Joplin (1937).

Group II.—Schists in which Glaucophane and Lawsonite are Important Constituents

A. Pumpellyite - lawsonite - glaucophane schists.—The mineralogy of these schistose rocks is simple; the only accessory minerals are chlorite, muscovite, sphene, and ilmenite. Lawsonite occurs as large twinned porphyroblasts in a matrix of glaucophane. Pumpellyite is commonly intimately associated with lawsonite but may occur in localized pockets with sphene and chlorite or in pure veins traversing the specimen.

An analysis of a pumpellyite-lawsonite-glaucophane schist (Table 1, a) closely resembles that of a Franciscan basalt and a normal tholeiitic basalt (Table 1, b and c). Crystallization of the schists from greenstones may be deduced from textural evidence. The first mineral to form after decomposition of all original constituents of the basalts was lawsonite. It appears as large clear or inclusion-fille deuhedral crystals. As recrystallization proceeded, pumpellyite became important in the groundmass and appears to have replaced lawsonite. Finally fine fibers of glaucophane crystallized, and as they increased in size, lawsonite tended to lose its clear outline. Sometime during this sequence, the rocks became traversed by veins of pumpellyite and lawsonite. In many of the specimens both minerals are clearly secondary; the clear idiomorphic grains filling the veins show a different character from the ragged, inclusion-filled grains.

B. Garnet-lawsonite-glaucophane schists.—In addition to glaucophane, garnet, and lawsonite schists of this group may contain muscovite, chlorite, calcite, pumpellyite (replacing lawsonite), sphene, and ilmenite. Except for muscovite the accessory minerals are present in minor amount. Glaucophane occurs as medium- to fine-grained twisted crystals that simulate flow structure near large crystals of lawsonite

TABLE 1.—ANALYSES OF GLAUCOPHANE SCHISTS

	a	b	c	d	e	f	g
SiO_2	48.29	46.60	50.83	52.28	51.28	73.72	71.72
TiO_2	1.37	2.87	2.03	1.34	2.96	0.38	0.35
Al_2O_3	14.62	15.28	14.07	16.81	12.04	10.53	13.23
Fe_2O_3	0.84	3.98	2.88	4.28	2.98	0.67	0.30
FeO	8.37	8.17	9.06	7.63	10.54	3.51	3.58
MnO	0.22	0.08	0.18	0.09	0.38	0.05	nil
MgO	8.33	5.14	6.34	6.09	7.76	2.82	1.81
CaO	10.24	10.68	10.42	2.46	3.95	2.44	1.80
Na_2O	2.47	2.26	2.23	3.37	4.49	1.72	2.72
K_2O	0.13	0.85	0.82	0.10	0.52	1.26	1.29
P_2O_5	0.12	0.36	0.23	n.d.	0.38	0.14	0.09
$H_2O + 105°C$	4.93	3.63	0.91	4.00	2.28	2.62	2.53
$H_2O - 105°C$	0.12	0.24	—	0.15	0.17	0.16	0.15
CO_2	nil	0.06	—	1.35	trace	trace	0.32
C	n.d.	n.d.	—	n.d.	n.d.	0.24	n.d.
SO_3	n.d.	0.08	—	n.d.	n.d.	n.d.	n.d.
ZrO_2	n.d.	n.d.	—	n.d.	n.d.	n.d.	0.04
Total	100.05	100.28	100.0	99.95	99.73	100.26	99.93
S.G.	3.11 ± .02	2.85	—	3.00 ± .02	3.20 ± .02	2.86 ± .02	n.d.

a. Pumpellyite-lawsonite-glaucophane schist, Junction School area, Healdsburg. W. Herdsman, analyst. Specimen is made up of approximately 60 per cent glaucophane, 30 per cent lawsonite, and 10 per cent pumpellyite with minor amounts of sphene and chlorite.

b. Basalt, 2 miles north of Camp Meeker, Sonoma County. F. A. Gonyer, analyst. (Switzer, 1945, p. 7). Stated MgO content corrected (Switzer, personal communication).

c. Normal tholeiitic basalt and dolerite—mean of 138 analyses. (Nockolds, 1954, p. 1021.)

d. Garnet-lawsonite-glaucophane schist, Junction School area, Healdsburg. R. J. Borg, analyst. Glaucophane makes up 80–90 per cent of the rock. Large lawsonite crystals containing inclusions makes up the remainder. Garnet & ilmenite are the only recognizable accessories.

e. Lawsonite-garnet-glaucophane schist, Junction School area. W. Herdsman, analyst. Specimen consists of approximately 80 per cent glaucophane, 12 per cent garnet, less than 3 per cent each lawsonite and muscovite, and minor sphene and ilmenite. Garnet is rounded and completely surrounded by laths of muscovite which occur sparingly elsewhere.

f. Lawsonite-glaucophane-quartz schist, Junction School area, Healdsburg. W. Herdsman, analyst. Quartz, glaucophane, and lawsonite make up 70 per cent, 25 per cent, and 5 per cent of the schist respectively. A brown fibrous unidentified material occurs in twisted stringers.

g. Fresh Franciscan sandstone from Carbona quadrangle. W. Herdsman, analyst. (Taliaferro, 1943, p. 136.)

and garnet. Lawsonite and garnet are typically filled with inclusions and are badly fractured. Generally the garnet is unaltered although it may rounded outlines. Where alteration is obvious, fractures of the garnet are filled with chlorite, and the whole is surrounded by muscovite.

Analyses of two members of the group (Table 1, d and e) are distinguished by low CaO contents. The high TiO_2 content is also distinctive in the lawsonite-garnet-glaucophane schist (Table 1, e). The parents are unknown. These schists show no textural, chemical, or mineralogical resemblances to the garnet-bearing glaucophane schists that were drived from eclogites and garnet-hornblende-pyroxene rocks.

Group III.—Schists in which Quartz and a Member of the Glaucophane-Riebeckite Series are Important Constituents

A. Lawsonite-glaucophane-quartz schists.—Well-lineated and foliated outcrops of this schist are common and are invariably traversed by quartz veins. Minute inclusions cause the lawsonite to be cloudy. An analysis of a member of the group is given in Table 1, f. The rock corresponds in composition to the arkosic wackes found throughout the Franciscan formation and adjacent to the schists in Healdsburg (Table 1, g). The analyses of Franciscan sandstones compiled by Taliaferro (1943) are distinguished from those of average sandstones by particularly high Al_2O_3 and Na_2O contents. These oxides are present in the feldspar, albite-oligoclase, which is abundant in the sandstones. The average Na_2O content of four is 3.97 per cent, but quantities up to 6.03 per cent have been recorded.

B. Crossite-quartz schists.—Members of this group are uncommon in the area. Quartz makes up 85–90 per cent of one specimen examined, and long needles of a member of the glaucophane-riebeckite family, designated crossite here, the remaining 10–15 per cent (X = yellow, Y = deep blue, Z = deep purple, b = Z, 2V = (−) 45°, $c \wedge X = 85°$). The schist probably is a recrystallized chert.

Group IV.—Rocks in which Pyroxene and/or Hornblende are Important Constituents

A. Eclogite.—Following the definition and recognition of eclogite as a distinct rock type by Haüy (1822), several studies and summaries were made of the diverse mineralogy of the eclogite group (Riess, 1878; Zirkel, 1894: Briére, 1920). Descriptions of the eclogites, hornblende-eclogites, and glaucophane-eclogites found in association with members of the glaucophane schist family were included in these studies together with those of the more common eclogitic types found in complexes of high metamorphic grade. In the past 35 years knowledge of the latter group has been greatly increased by detailed studies, e.g., by Eskola, Alderman, and Davidson; and it has become increasingly difficult to adopt the refined nomenclature and genetical conclusions resultant on these studies for eclogites and eclogitelike rocks occurring in association with glaucophane schists. For clarity, in this discussion the name eclogite will be applied only to massive, granular rocks consisting dominantly of red garnet and pyroxene (omphacite) and containing minor accessory minerals, up to 10 per cent, of either primary or secondary origin. This is essentially Haüy's original definition.[1] In contrast to the diopside-jadeite and pyrope-almandite garnet typical of eclogites occurring in regions of deep-seated metamorphism, the Californian eclogites contain an acmitic pyroxene and almandite-rich garnets. They thus appear to be mineralogically atypical, although acmitic pyroxenes and pyrope-poor garnets occasionally occur in eclogites associated with members of the granulite facies (Eskola, 1920, p. 172–4; 1921, p. 31–6).

Unaltered eclogite occurs in discontinuous outcrops or in small masses on the sides of larger outcrops of hornblende and glaucophane schist. Foliation is never well developed, but banding is commonly conspicuous, though irregular in trend. Filling of fractures by rutile, apatite, muscovite, and glaucophane is characteristic of all exposures. With few exceptions the rocks are granoblastic. Garnet and pyroxene make up 90–95 per cent of the specimens. Rutile is a constant associate, and chalcopyrite and pyrite are common accessories. Cyanite does not occur.

The general term omphacite has been applied to the colorless to green pyroxene of the Californian eclogites (Holway, 1904; Switzer, 1945). However, pyroxene of this type is not restricted to eclogites; it also occurs as a relic in glaucophane and hornblende schists. Zoning, strong dispersion, mottled extinction, and fracturing are prominent features. The pleochrism of the group is X = pale green to apple green, Y = pale green, Z = colorless to pale yellowish green. The range of optical properties in 14 specimens is shown in Table 2.

[1] "Dans (cette roche), la diallage est considérée comme faisant la fonction de base et forme avec le grenat une combinaison binaire à laquelle sont s'unir accidentellement le disthene, le quarz, l'épidote et l'amphibole laminaire. J'ai donné a cette roche le nom d'eclogite . . .". R. Haüy, *Traite Minéralogié*, 1822, p. 456.

In the third group of rocks listed in Table 2, the pyroxene is unstable as judged by the deep-brown iron stain surrounding the grains De Roever (1947) and Quitzow (1935) describe similar staining about jadeite-aegirine in glaucophane-bearing rocks. In this suite the staining is conspicuous in rocks containing appreciable amounts of glaucophane.

TABLE 2.—OPTICAL PROPERTIES OF PYROXENE*

Nature of rock	No. of specimens	2V	$c\Lambda Z$	n_X	n_Y	n_Z
				(Sodium light)		
Eclogite	5	68°–86°	41°–54°	1.683–1.691	1.689–1.697	1.697–1.710
Chloritized eclogite	2	67°–78°	46°–58°	1.690	1.697	1.706–1.708
Relics in glaucophane and hornblende schists	7	72°–88°	43°–55°	undet.	undet.	undet.

* In any one specimen the average range of 2V is 8°, $c\Lambda$ Z, 4°. Individual measurements of optical angles are ± 1°, refractive indices ± .002.

The only chemical analysis of pyroxene in glaucophane-bearing rocks is that published by Birch (1943) and Switzer (1945) and quoted in Table 3. The analysis is similar to those recorded by Eskola (1921), Alderman (1936), and Briére (1920) for the diopside-jadeite of eclogites. It is distinguished by particularly large percentages of Fe_2O_3 and Na_2O, which together with SiO_2 make up the acmite end member. In order to facilitate further comparison, the Healdsburg pyroxene was calculated in the manner of Eskola (Table 3). It contains a considerable proportion of acmite, although not enough to warrant the name chloromelanite, *i.e.*, a diopside-jadeite rich in acmite. However, the deep color, high refractive indices, 2V, extinction angle, and dispersion of other pyroxenes in the suite suggest that acmite is present in molecular quantities on the order of 20 per cent. In these instances the name chloromelanite may be in order.

The garnets of the eclogites have much in common with those of the glaucophane schists; most important is their similar chemical composition. In addition most of the garnets are badly fractured and filled with minute inclusions. All show signs of decomposition to varying degree since they are commonly surrounded by sheaths of chlorite and/or muscovite containing large crystals of epidote and/or pumpellyite. In some specimens only a pseudomorph composed of chlorite dotted with inclusions remains. The inclusions are commonly too small to permit positive identification; however, sphene, rutile, an opaque ore, a member of the clinozoisite-epidote group, and a mineral whose properties suggest feldspar are a few of the minerals that are included.

The composition of the garnets occurring in glaucophane-bearing rocks has been treated by Pabst (1931; 1955). The rocks bearing the garnets investigated by Pabst are not always schistose, nor is glaucophane a major constituent in all. At least one is an eclogite (Pabst's II), two are hornblende rocks (I and A), and one is a glaucophane schist (B). The New Caledonian garnet is from a schist, but a petrographic description is lacking. The composition of the group is surprisingly uniform considering the diversity of the enclosing rocks.

Schürmann (1950) using these data together with two other analyses of garnets from "amphibolite-glaucophanites" noted that the average composition of the group differs markedly from the average composition of the garnets of the eclogites. In order to incorporate new data and to calculate all analyses on the same basis, a new compilation is presented here (Table 5). A new analysis of a garnet occurring in the eclogites of Healdsburg is shown in Table 4. In calculation of mole per cent of end members in garnets of Table 5, TiO_2 is considered part of the andradite unit, and water, which is insignificant in most analyses, has been omitted. Suzuki's analysis contains only the total iron content. For calculation the Fe_2O_3 content was

set at 4.63 per cent. The ratio $RO:R_2O_3:SiO_2$ thereby becomes 3.00:1:2.92.

Group I of Table 5 consists of eight garnets of eclogites occurring in areas devoid of glaucophane and believed to represent the highest grade of metamorphism. Group II is made up of seven garnets occurring in glaucophane-bearing rocks. It includes garnets of two eclogites in which glaucophane is of minor importance. Table 5 shows that:

(1) Garnets of the first group show a wider range in composition that those of Group II. By and large the former are garnets rich in almandite and pyrope.

(2) Garnets of the second group show a narrow range of variation. There is little difference in the composition of the garnets of the Californian eclogites and those of the glaucophane schists.

(3) Garnets of the Californian eclogites fall within the range defined by Group I, but they show greater affinities to garnets of Group II. Specifically, their pyrope content, less than 20 per cent, is much lower than that of the average garnet of the European eclogite group, and their almandite, andradite, and grossularite contents are proportionately higher. The difference in almandite and pyrope contents is more clearly illustrated in Figure 4.

The garnets occurring in garnet amphibolites, hornblende gabbros, norites, and labradorite rocks which are commonly associated with eclogites have not been included in either group. Garnets of norites and labradorite are

TABLE 3.—PYROXENE ANALYSES

	a	b	Diopside		Jadeite		Acmite		Unaccounted		M.q.
			M.q.	Wt.	M.q.	Wt.	M.q.	Wt.	M.q.	Wt.	
SiO_2	54.03	53.31	0.498	29.90	0.280	16.82	0.104	6.24	0.006	0.36	0.888
Al_2O_3	11.54	10.52			0.070	7.16			0.033	3.36	0.103
TiO_2	0.54	0.26							0.003	0.26	0.003
Fe_2O_3	5.62	4.11					0.026	4.11			0.026
FeO	4.09	2.84	0.040	2.84							0.040
MnO	0.05	0.05	0.001	0.05							0.001
MgO	5.13	8.42	0.208	8.42							0.208
CaO	11.82	14.50	0.249	13.99					0.009	0.50	0.258
Na_2O	6.81	5.90			0.069	4.28	0.026	1.62			0.095
K_2O	0.20	0.05			0.001	0.05					0.001
$H_2O + 110°C$	0.29	0.16							0.009	0.16	0.009
	100.12	100.12		55.20%		28.31%		11.97%		4.64%	

	a	b
S.G.	3.365	3.34 ± 0.02
cNZ	41°	44°–50°
2V	(+)82° 40′	(+)70°–82°
n_y	1.697 ± .002	1.692 ± .002
n_x		1.688 ± .002
n_z		1.710 ± .002
Dispersion	Strong r > v	Moderate r > v

	b	a	
Diopside	55.20	40.77	$Ca(Mg, Fe'', Mn)Si_2O_6$
Jadeite	28.31	34.82	$(Na, K)AlSi_2O_6$
Acmite	11.97	12.00	$NaFe'''Si_2O_6$
Pseudo-jadeite		10.47	$(Ca, Mg)(Al, Fe''')_2Si_4O_{12}$
Unaccounted	4.64	2.06	
	100.12	100.12	

a. Chloromelanite from chloromelanite-eclogite. P. Eskola, analyst. (Eskola, 1921, p. 32–3.)

b. Acmitic diopside-jadeite from eclogite (H6), Healdsburg. F. Gonyer, analyst. (Birch, 1943, p. 272.) Optical properties recorded by Switzer (1945, p. 5) could not be duplicated, and those recorded above were determined by the author and checked by F. J. Turner.

rich in pyrope. (Eskola, 1920, p. 172). The garnets of the amphibolites and gabbros are similar in composition to the Californian under which crystallization or amphibolitization took place. By this reasoning the California eclogites and related garnetiferous schists

TABLE 4.—GARNET ANALYSIS*

		Molecular quotient	
SiO_2	37.26	0.620	0.620
TiO_2	0.54	0.007	
Al_2O_3	20.12	0.197	0.220
Fe_2O_3	2.60	0.016	
FeO	25.18	0.351	
MnO	0.92	0.013	0.612
MgO	2.96	0.073	
CaO	9.83	0.175	
$H_2O - 105°C$	0.04	RO:R_2O_3:SiO_2	
$H_2O + 105°C$	0.09	2.78:1:2.82	
	99.54		
S.G.	4.08 ± 0.02	$a_o = 11.62 \mp 0.01$ Å	
n_{Na}	1.795 ± 0.003		

Mole per cent of end members

Almandite	57.4
Pyrope	11.7
Spessartite	2.0
Andradite	9.8
Grossularite	19.1
	100.0

* Garnet from eclogite (H49), Junction School, Healdsburg quadrangle. Analyst, W. Herdsman.

garnets as they typically have high almandite, low pyrope contents.

Undoubtedly some garnet amphibolites formed through retrograde metamorphism of eclogites; however, various workers have suggested that most have an independent origin. Wang (1939) demonstrated that the two rocks are close in composition but that the garnets of the two types of rock are not isochemical. Eskola (1920, p. 187) similarly noticed this discrepancy and wrote "The garnet amphibolites might be relic eclogites, but as they invariably bear almandite garnet, it seems that more magnesian garnets are not likely to be preserved as relics, and we have no traces left of them." The ratio of almandite to pyrope would seem to be determined by the conditions formed under conditions more closely allied to those of the garnet amphibolite than those of the eclogite facies. From all indications garnets occurring in glaucophane schists formed independently of eclogites, also included in Group II (Table 5), differ in no significant way from the other garnets of the group.

An analysis of an eclogite is given in Table 6 together with that of the Coyote Creek eclogite and a Franciscan basalt. The total iron content of the two eclogites differs by 12.09 per cent. There is some question as to the reliability of the analysis of the Coyote Creek eclogite because its composition is reconciled with difficulty to its mineralogical description. The analyses of the Healdsburg eclogite and basalt show a marked similarity, an observation in

TABLE 5.—PER CENT OF END MEMBERS IN GARNETS OF ECLOGITES AND GLAUCOPHANE-BEARING ROCKS

Group I									Group II						
Eclogite; Heaner, 1903	Eclogite; Briére, 1920	Eclogite; Eskola, 1921	Eclogite; Eskola, 1921	Eclogite; Eskola, 1921	Eclogite; Dull, 1903	Eclogite; Alderman, 1936	Eclogite; Davidson, 1943		Eclogite, Coyote Creek; Smith, 1907	Eclogite, Healdsburg	Hornblende schist (Russian River) Pabst, 1931; 1955	Hornblende schist (?) (Hilton Gulch) Pabst, 1931; 1955	Glaucophane schist (Reeds Station) Pabst, 1931; 1955	Hornblende schist Suzuki, 1930	Glaucophane schist (New Caledonia) Pabst, 1931
43	38	57	41	26	29	38	43	almandite	51	57	48	47	54	50	47
35	34	16	43	61	52	42	29	pyrope	20	12	16	19	9	18	19
n.d.	n.d.	2	1	1	0	1	1	spessarite	n.d.	2	0	4	5	6	12
17	4	7	7	3	8	4	5	andradite	10	10	15	23	3	15	n.d.
5	24	19	8	9	10	15	22	grossularite	19	19	21	7	29	11	22
100	100	101	100	100	99	100	100		100	100	100	100	100	100	100

Average of eight		Average of seven
40	almandite	50
39	pyrope	16
1	spessarite	5
7	andradite	13
14	grossularite	17
101		101

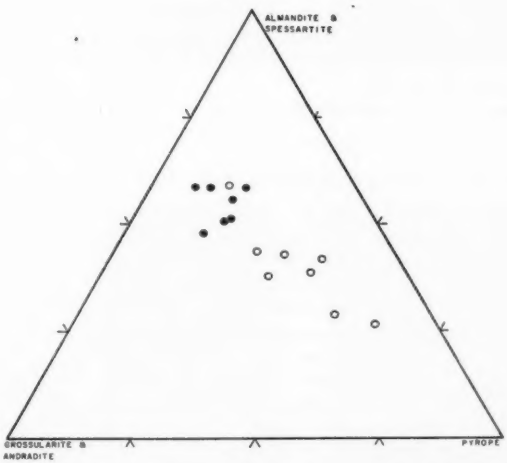

FIGURE 4.—COMPOSITION OF GARNETS OCCURRING IN ECLOGITES AND GLAUCOPHANE-BEARING ROCKS

Mole per cents of end members in several eclogite garnets (Group I, Table 5) are indicated by open circles; those of garnets of glaucophane-bearing rocks (Group II, Table 5) are indicated by solid circles.

TABLE 6.—ANALYSES OF ECLOGITES

	a	b	c	d	e
SiO_2	48.60	44.15	46.60	43.48	44.61
TiO_2	1.12	trace	2.87	2.32	3.21
Al_2O_3	14.04	10.18	15.28	13.96	15.68
Fe_2O_3	3.49	11.92	3.98	2.43	1.81
FeO	9.38	13.04	8.17	13.35	15.88
MnO	0.26	n.d.	0.08	0.31	0.28
MgO	6.56	6.18	5.14	10.16	5.70
CaO	11.87	4.51	10.68	8.52	7.37
Na_2O	3.86	5.11	2.26	2.20	2.70
K_2O	0.22	2.09	0.85	0.43	1.89
P_2O_5	trace	n.d.	0.36	trace	n.d.
$H_2O + 105°$	0.58	0.95	3.63	2.46	n.d.
$H_2O - 105°$	0.12	n.d.	0.24	0.18	0.52
CO_2	nil	n.d.	0.06	trace	n.d.
SO_3	n.d.	n.d.	0.08	n.d.	n.d.
Total	100.10	99.31	100.28	99.80	99.65
S.G.	3.45	3.53	2.85	3.18 ± .02	3.20

a. Eclogite (H6), Junction School, Healdsburg. W. Herdsman, analyst. Acmitic diopside-jadeite and magnesian almandite make up 96 per cent of the specimen. Chlorite, rutile, sphene, chalcopyrite, pyrite, and glaucophane are accessories.

b. Eclogite, Coyote Creek, Santa Clara Co. C. B. Allen, analyst. Pyroxene, garnet with minor muscovite, glaucophane, and actinolite (hornblende?). (Holway, 1904, p. 347–50, 356). Note: analysis does not add to total specified.

c. Franciscan basalt, Camp Meeker, Sonoma Co. F. A. Gonyer, analyst. (Switzer, 1945, p. 7). MgO content corrected (Switzer, Personal communication).

d. Garnet-hornblende rock with remnant pyroxene (H 128B), one fourth mile north of Junction School, Healdsburg. W. Herdsman, analyst. Hornblende and chloritized garnet are major constituents. Pumpellyite is localized within chlorite sheaths together with epidote. Stained pyroxene, epidote, muscovite, rutile, sphene, and glaucophane are accessories.

e. Eclogite-hornblende gabbro, Romsdalshorn, Norway. P. Eskola, analyst. (Eskola, 1921, p. 43).

PLATE 1.—PHOTOMICROGRAPHS OF ALTERED ECLOGITE AND GLAUCOPHANE SCHISTS

In plane polarized light

FIGURE 1.—SLIGHTLY CHLORITIZED ECLOGITE

Inclusion-filled garnets are surrounded by chlorite which also occurs elsewhere in slide.

FIGURE 2.—GARNET-PYROXENE-HORNBLENDE ROCK, H 128

Rounded aggregate of chlorite pseudomorph after garnet occurs in a groundmass of hornblende, pyroxene (arrows), sphene, and glaucophane. Chlorite contains clear crystals of epidote, pumpellyite, sphene. Partially altered garnet occurs elsewhere in specimen.

FIGURE 3.—EPIDOTE-MUSCOVITE-HORNBLENDE SCHIST WITH REMNANT PYROXENE, H 134

Edges of the ragged pyroxene grains, indicated by arrows, are deeply stained. Chlorite, pumpellyite, and sphene are accessories.

FIGURE 4.—MUSCOVITE-CHLORITE-GLAUCOPHANE SCHIST WITH REMNANT GARNET

Typical alteration of garnet; chlorite filled with inclusions of sphene and surrounded by concentrically aligned laths of muscovite. Remnants of garnets are not shown.

FIGURE 5.—MUSCOVITE-GLAUCOPHANE SCHIST WITH REMNANT PYROXENE, H 48B

Coarse-grained glaucophane occurs with muscovite, chlorite, sphene, and a green pyroxene. The pyroxene, indicated by arrows, shows jagged and stained boundaries.

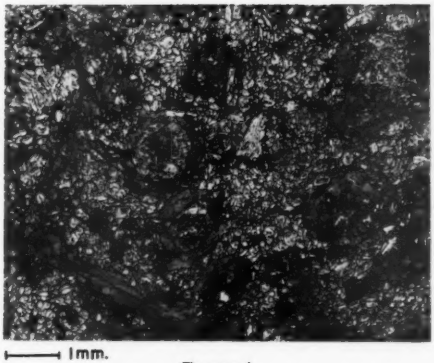

FIGURE 1

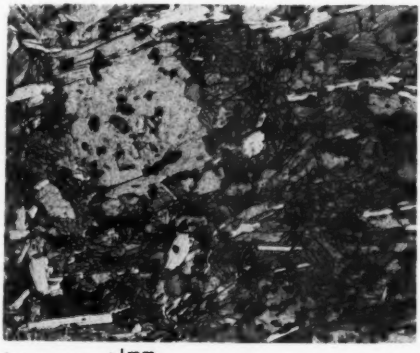

FIGURE 2

FIGURE 3

FIGURE 4

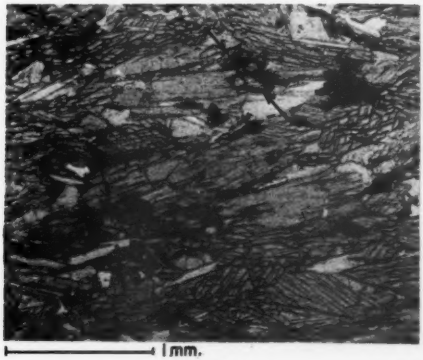

FIGURE 5

PHOTOMICROGRAPHS OF ALTERED ECLOGITE AND GLAUCOPHANE SCHISTS

keeping with the conclusions of those European geologists who consider that eclogites are derived from normal gabbros.

B. Chloritized eclogites.—Chloritized eclogites are pyroxene-garnet rocks in which secondary minerals such as chlorite, muscovite, and sometimes glaucophane constitute more than 10 per cent (Pl. 1, fig. 1). They are generally without planar structure. Garnet is recognized with difficulty in hand specimen, as alteration to chlorite is extensive. Zoned pyroxene is faintly pleochroic in green, and its optical properties are identical with pyroxenes of the eclogites proper. Epidote and muscovite are confined to sheaths of chlorite surroundings the garnet. Chlorite occurs in such abundance that it must be assumed that pyroxene as well as garnet is undergoing alteration. Contacts of chlorite and pyroxene are jagged. Sphene, rutile, and chalcopyrite occur in small amount. In some specimens glaucophane is pseudomorphic after pyroxene.

C. Pyroxene-chlorite rocks with and without epidote.—Members of this group are highly altered eclogites in which pyroxene is the only original constituent in abundance. One well-foliated member is made up of pyroxene (30 per cent), chlorite (30 per cent), epidote (20 per cent), muscovite, sphene, chalcopyrite, and a few grains of glaucophane (10 per cent). Epidote and a pale-green chlorite are dispersed throughout; there is no evidence that they formed at the expense of garnet, although this is a probable origin.

Another member of the group is without foliation and is essentially bimineralic; pyroxene (45 per cent) and chlorite (50 per cent) are the only minerals in notable quantity. Large green pyroxene grains are made conspicuous by wide brown borders. Chlorite appears to be derived from the breakdown of pre-existing garnet and pyroxene. Sphene, glaucophane, muscovite, and epidote are present in minor amount.

D. Garnet-pyroxene-hornblende rocks.—Rocks of this group have been called "hornblende eclogites" by Holway (1904) and Crittenden (1949, PhD. thesis, Univ. of Calif.; 1951). They are without schistose structure and are characterized by the presence of blue-green hornblende, almandite garnet in all stages of alteration, and green pyroxene, which, judging from the brown stain surrounding it, is undergoing decomposition. The pleochroism of hornblende is: X = colorless to pale yellow; Y = bright green to olive green; Z = deep blue to greyish blue green. The variation in optical properties as expressed in 10 specimens is $2V = (-)\ 60°–79°$, $c\wedge Z = 12°–22°$. Chlorite, muscovite, epidote, pumpellyite, and glaucophane replacing hornblende, show all degrees of development. The conspicuous absence of plagioclase in these rocks, as well as in the suite as a whole, makes the term amphibolite inapplicable.

Schists containing a greenish-blue amphibole are commonly associated with glaucophane-bearing rocks. The association also has been described in Venezuela (Schürmann, 1950, p. 116; Dengo, 1953, p. 25), Japan (Suzuki, 1930, p. 42), Anglesey (Greenly, 1919, p. 116), and Celebes (de Roever, 1947, p. 160). However the common association of hornblende with large amounts of pyroxene is unique to California. The three most common mineral assemblages in Healdsburg are garnet-pyroxene-hornblende rocks (Pl. 1, fig. 2), garnet-hornblende rocks with remnant pyroxene, and garnet-hornblende-epidote rocks with remnant pyroxene. Where hornblende and pyroxene occur together, hornblende does not obviously replace pyroxene although it may completely surround that mineral. Both may be in contact with garnet without an intervening layer of chlorite.

An analysis of a garnet-hornblende rock with remnant pyroxene is presented in Table 6, d. Many features of this rock suggest that it is an amphibolized eclogite: the green pyroxene is clearly a remnant, and the garnet is fractured and altered. Yet the two rocks have a distinctly different composition (Table 6, a and d). The eclogite corresponds in composition to a basic igneous rock, whereas the garnet-hornblende rock because of its low SiO_2 and high FeO, Fe_2O_3, and MgO contents corresponds to an ultrabasic igneous rock. The comparison does not rule out the possibility that this rock is derived from an eclogite. An analysis of an eclogite-hornblende gabbro is quoted in Table 6 to show that eclogites may have a decided ultrabasic character. It appears unlikely that all the differences in composition between the

Healdsburg eclogite and garnet-hornblende rock are due to exchange of ions during alteration.

E. Pyroxene-hornblende rocks.—Rocks of this category may be structureless or well foliated. Two common types are pyroxene-hornblende rocks and epidote-muscovite-hornblende schists with remnant pyroxene. The pyroxene, which is clustered in ragged aggregates and usually stained, may be present in amounts up to 20 per cent (Pl. 1, fig. 3). Hornblende, in part replaced by glaucophane, does not appear to replace pyroxene although the two are closely associated. In the unfoliated rocks chlorite occurs in aggregates which suggests that it has there completely replaced garnet. Muscovite, epidote, pumpellyite, and sphene are commonly associated. A pyroxene-hornblende-muscovite-chlorite rock was found to contain 45.1 per cent SiO_2.

Group V.—Schists in which Glaucophane, Epidote, and/or Micas are Important Constituents

Within Group V the following five subdivisions have been delineated on the basis of the presence of various minerals that occur in addition to glaucophane:

(1) Garnet-epidote-glaucophane schist with or without remnant pyroxene
(2) Garnet-muscovite-glaucophane schist with and without remnant pyroxene
(3) Muscovite-glaucophane schist with and without remnant pyroxene
(4) Garnet-chlorite-glaucophane schist with and without remnant pyroxene
(5) Chlorite-(muscovite)-glaucophane schist with and without remnant hornblende

All but one subdivision contain both pyroxene-bearing and pyroxene-free varieties. The pyroxene is relict and occurs in small stained grains (Pl. 1, fig. 5). The garnet where present is filled with inclusions among which pyroxene can be recognized. Slight alteration to chlorite is common. Muscovite concentrically surrounds garnets in muscovite-rich schists (Pl. 1, fig. 4). Hornblende can be seen in cores of some glaucophane crystals, notably in those specimens lacking pyroxene and garnet. In all members sphene, ilmenite, and apatite are present.

Relations within and between Groups IV and V

Rock and schists such as described in Groups IV and V have been found throughout the Coast Ranges. This suite is distinguished by the ubiquitious occurrence of green pyroxene: a main constituent in the eclogites and an inconspicuous and quantitatively unimportant relic in amphibole-rich rocks. The optical properties indicate that the pyroxene of both occurrences is the same. In addition, the garnet in all these rocks is almandite with minor amounts of pyrope, grossularite, and andradite. These observations suggest that many of the glaucophane and hornblende schists may have originated through retrograde metamorphism of pre-existing pyroxene-garnet rocks.

The course of recrystallization in Californian eclogites is quite different from that recorded for eclogites occurring in gneissic areas. In other parts of the world retrogression gives rise to a myrmekitelike, plagioclase-diopside symplectite replacing omphacite and to a kelyphitic mantle of green hornblende surrounding remains of garnet. The final product is granular amphibolite with or without garnet. In the Californian rocks no sign of these intergrowths is found although hornblende is commonly present. The most obvious explanation is that retrogression proceeded along entirely different lines and that the change in physical conditions leading to the alteration of the Californian eclogites is more radical than the change associated with the amphibolization of the European eclogites. Instead of recrystallizing in the amphibolite facies, the eclogites have undergone retrogression in an environment comparable to that of the albite-epidote-amphibolite or greenschist facies. Ultimate conversion of these rocks to glaucophane schists is an additional and later stage in the alteration.

Several lines of descent by retrograde metamorphism may be formulated by examination of the mineral components of the rocks (Table 7); however, the position of hornblende within the sequence is not clear. If an eclogite had shown incipient growth of hornblende, an explanation of all rock types might be forthcoming. Such a rock was not found here and to the writer's knowledge has not been described

elsewhere in California. Usually wherever pyroxene and hornblende occur together, pyroxene is subordinate and undergoing decomposition. Hornblende does not replace pyroxene. In a few specimens grains of clear, assemblages can be followed. It is one of three lines of descent that may be recognized within the rocks examined; the other two stem directly from the eclogites. The three sequences are schematically presented in Table 8.

TABLE 7.—RESUMÉ OF MINERAL ASSEMBLAGES IN PYROXENE- AND HORNBLENDE-BEARING ROCKS

Specimen	Pyroxene	Garnet	Hornblende	Chlorite	Muscovite	Epidote	Pumpellyite	Glaucophane	Group
H6	x	x		o	o			o	
H189	x	x			o				
H50	x	x		o	o			o	Eclogites IVA
H49	x	x		o	o			o	
H216	x	x		o	o				
H11	x	x		x	o	o		o	Chloritized eclogites IVB
H82	x	x		x	o	o		o	
H79	x			x	o	x		o	Pyroxene-epidote-chlorite rocks IVC
H240	x (stained)			x	o			o	
H128	x	x	x	o	x	o	o	o	
H254	x	x	x	o	o	o		o	Garnet-pyroxene-hornblende rock IVD
H19	x (stained)	o	x	o		o		o	
H128B	o (stained)	x	x	o	o	o	o	o	
H129	o (stained)	x	o	o	o	x		o	
H53	x (stained)		x	x	x	o	o	o	Pyroxene-hornblende rock IVE
H134	o (stained)		x	o	x	x	o	o	
H1	o (stained)	x		o	o			x	
H19B	o (stained)	o		x				x	
H48B	o (stained)			o	o			x	Glaucophane schists V
H164	o (stained)	x		x	o	x		x	
H2			o (remnant)	x				x	
H39			o (remnant)	x	x			x	

x = important constituent (greater than 10 per cent). o = present in minor quantity.

unaltered pyroxene are adjacent to hornblende (Pl. 1, fig. 2). They do not show replacement boundaries, and their mutual relation suggests that they crystallized together. Two alternative origins for the hornblende are:

(1) Hornblende is a product of retrograde metamorphism under conditions simulating those of the albite-epidote-amphibolite facies.

(2) Hornblende is a primary constituent in the pyroxene-garnet rocks, having crystallized simultaneously with the pyroxene. In Davidson's terminology (1943) these would be true hornblende eclogites.

Although it is not possible to decide between the above alternatives, retrograde metamorphism of the garnet-pyroxene-hornblende

The garnet-pyroxene-hornblende rocks gave rise to rocks in which epidote and chlorite are important constituents under retrograde conditions. An early stage in retrogression was the absorption of pyroxene, which is shown by diminished grain size, a brown staining around each grain, and irregular boundaries. It is not possible to say whether hornblende grew at the expense of pyroxene. The fact that blue-green amphiboles generally contain more iron than was available in the pyroxenes, and the probability that the brown staining about the pyroxene is an iron oxide exsolved out of the pyroxene not utilized in the formation of other minerals make it unlikely that the hornblende was an alteration product of pyroxene. Garnet

largely remained unaltered. As the pyroxene became less important, chlorite, epidote, and muscovite occur in greater abundance. Finally the garnet underwent extensive chloritization. go replacement by chlorite. Pyroxene simultaneously broke down to chlorite and epidote, but it persisted long after the garnet had been absorbed. Retrogression was from

TABLE 8.—RETROGRADE METAMORPHISM OF ECLOGITES

Relict minerals designated by italics.

Equivalent metamorphic facies	Eclogite (Group IVA)		
Albite-epidote-amphibolite facies	Garnet-hornblende-pyroxene rocks (Group IVD)		
Greenschist facies	*Pyroxene-hornblende* rocks with chlorite muscovite, and/or epidote (Group IVE)	Chloritized eclogites (Group IVB)	
		Pyroxene-chlorite-epidote rocks (Group IVC)	
Glaucophane schist facies	Chlorite-glaucophane schist with remnant *hornblende* (Group V)	Chlorite and muscovite glaucophane schists with remnant *pyroxene* (Group V)	*Garnet* - epidote glaucophane schists with remnant *pyroxene* (Group V)
			Garnet - muscovite glaucophane schists with remnant *pyroxene* (Group V)
			Garnet - chlorite glaucophane schists with remnant *pyroxene* (Group V)

The unaltered condition of the garnet in some rocks that otherwise appear to have undergone retrogression suggests that the garnet was stable under some of the retrograde conditions. It is possible that the retrogression proceeded under conditions equivalent to the albite-epidote-amphibolite facies where only the pyroxene was unstable. The breakdown of the garnet occurred when further changes in the physico-chemical conditions produced an environment similar to that of the greenschist facies.

Another line of descent is represented by the chloritized eclogites and pyroxene-epidote-chlorite rocks which were derived directly from eclogites. Garnet was the first mineral to undereclogite directly to a mineral assemblage of the greenschist facies.

The third line of descent is represented by schists in which glaucophane developed in sufficient quantity to obliterate nearly all traces of the parent. In some instances the immediate parent was eclogite, and in others it was a member of one of the other two sequences of retrograde metamorphism. Those glaucophane schists derived directly from eclogites contain a slightly altered garnet together with quantitatively insignificant pyroxene. Chlorite-glaucophane schists containing remnant hornblende stemmed from some member of the first mentioned sequence of retrogression. The group of chlorite and epidote-rich glaucophane schists

containing relicts of pyroxene probably derived from the chloritized eclogites, *e.g.* H19B and H1 of Table 7, or from the pyroxene-epidote-chlorite rocks, *e.g.* H164 and H48B of Table 7. It appears likely that by the time glaucophane began to crystallize, some of the eclogites had already undergone retrograde metamorphism. The eclogite and its derivatives representing two and possibly three facies were all modified by a final change in physico-chemical conditions shown by their sometimes complete recrystallization to glaucophane schists.

The three lines of descent include most of the mineral assemblages found, and it is probable that the genesis of these schists is more complex than the one here outlined. Solutions played an essential part in the formation and modification of the rocks, but it is impossible to evaluate their precise *modus operandi*. It has not been positively demonstrated that the garnet-pyroxene-hornblende rocks are derived from eclogites. The tentative view adopted by the writer is that the hornblende is secondary and that variation in mineralogical assemblages has been determined mainly by the variable composition of the parent rock (eclogite) and only slightly modified by hydrothermal solutions.

Because schists consisting dominantly of glaucophane occupy positions in each of the three sequences of retrograde metamorphism, it is desirable to distinguish the accompanying relict minerals from minerals formed contemporaneously with glaucophane. Minerals forming contemporaneously with glaucophane are not always easily distinguished from those forming immediately preceding its introduction. In fact, it is possible that such minerals as epidote and chlorite remain stable under conditions favoring the development of glaucophane. Thus the best guide to minerals originating simultaneously with glaucophane is found in schists whose immediate parents are members of the geosynclinal suite. A synthesis of minerals occurring in the Californian glaucophane schists is presented in Table 9.

TABLE 9.—MINERALS OF THE GLAUCOPHANE SCHISTS

[a] Derived from Franciscan sediments and lavas	[b] Derived from eclogites
Glaucophane-crossite	Primary
Jadeite-acmite*	Acmitic diopside-jadeite
Magnesian almandite	Magnesian almandite
Lawsonite	Rutile
Pumpellyite	Sulfide minerals
Muscovite	Retrograde
Albite*	Blue-green hornblende†
Epidote group	Epidote
Stilpnomelane*	Muscovite
Chlorite	Chlorite
Quartz	Pumpellyite
Calcite	Glaucophane
Prehnite*	Sphene
Sphene	
Ilmenite	

* Minerals absent or rare in rocks under review.
† Status uncertain.

Chlorite Bands Containing Nodules of Actinolite

Intimately associated with the hornblende and glaucophane schists are narrow bands of almost pure chlorite containing oblong nodules of actinolite. Generally the nodules are scattered on the ground, disassociated from their chlorite sheath. Together with chlorite they constitute bands usually less than 6 feet in length with a well-defined but irregular foliation. The trend of the bands conforms to the general regional pattern. In a few outcrops the nodules occur as coarse aggregates on the weathered sides of the rock.

The dimension of the nodules ranges from 2–10 inches, but much larger lenses have been found elsewhere. They consist almost exclusively of pure actinolite; sphene, chlorite, and glaucophane are the only accessories. Talc has been reported to surround some of the nodules, but it was not recognized in those examined.

Taliaferro (1943) and Brothers (1954) report nodules of actinalite within serpentinite. In Healdsburg they are associated with the eclogites, hornblende, and glaucophane schists and were not found with serpentine. There can be little doubt that they are genetically related to an ultrabasic rock, however. The composition of actinolite and chlorite in appropriate proportions has been shown by Taliaferro to be equivalent to that of serpentine. In addition actinolite-talc-chlorite schists are commonly derived from ultrabasic rocks in the green-

schist facies. Taliaferro (1943), Read (1934) and Chenevoy (1950), who describe similarly zoned nodules occurring within gneisses, concluded that diffusion between peridotite and surrounding rocks modified their original composition.

Summary of Field and Petrographic Relations

The most pertinent information on the field relations, mineralogy, and petrography of the rocks in the area is summarized below.

(1) Glaucophane schists, hornblende rocks, and eclogites occur in a localized area together with a narrow sill of serpentinite within the Franciscan formation. The formation is an altered but unmetamorphosed series of typical geosynclinal sediments and eruptives.

(2) The rocks occurring in the area, exclusive of serpentinite, are basic and highly siliceous types. Intermediate types (53–66 per cent SiO_2) are not represented. The basic schists and greenstones are adjacent to the serpentinite sill. The eclogites and related hornblende rocks occur in a discontinuous belt 300 feet or more from the serpentinite; in the area around the Junction School they occur within a few feet of the serpentinite. Although several large bodies of glaucophane schist are completely surrounded by serpentinite, a contact between the two was not observed. The siliceous schists occur within a well-defined area northeast of the basic rocks.

(3) The glaucophane schists and some of the hornblende schists crystallized under stress, as shown by well-defined foliations and lineations. Features of their fabrics such as preferred orientation of minerals, snowball garnets, and flowing of minerals around others are further evidence that movement was concomitant with crystallization. Other rocks found in the area, *e.g.*, eclogite, chloritized eclogite, and some hornblende rocks, show signs of deformation in fracturing and undulatory extinction of component minerals, but generally do not have the tectonic character of highly deformed rocks.

(4) Within the region investigated, many outcrops, as judged by the attitude of their schistosities, have migrated. There are no continuous outcrops except within the belt of serpentinite. Despite the general irregularity, which is typical of the unmetamorphosed Franciscan formation, some general trends may be recognized. The foliation trends N. 55° W. and dips 25° N. A poorly defined fold axis trends N. 75° E. and plunges 25° NE. Folding is believed to have taken place in the late Jurassic simultaneously with the crystallization of the schists.

(5) It appears likely that the amount of structure evident in the rocks is related to the nature of the parent rock. From all indications the schists with the strongest planar and linear structures are derived from sediments. The massive pyroxene-bearing rocks and greenstones are derived from basic igneous rocks.

(6) The following general rock types may be recognized:

a. Greenstones
b. Pumpellyite-lawsonite-glaucophane schists
c. Lawsonite-glaucophane-quartz schists
d. Crossite-quartz schists
e. Garnet-lawsonite-glaucophane schists
f. Eclogite and chloritized eclogites
g. Garnet-hornblende rocks and hornblende schists with remnant pyroxene
h. Muscovite-chlorite-epidote-glaucophane schists with remnant garnet

(7) The greenstones are altered basaltic flows in which the original mineral constituents cannot be recognized. Some gave rise to pumpellyite-lawsonite-glaucophane schists.

(8) The quartz-rich schists are derived from cherts and sandstones. Metacherts are not abundant in this area; most of the siliceous rocks have been shown to be related to surrounding arkosic wackes.

(9) Garnet-lawsonite-glaucophane schists show no relationship to eclogites, garnet-hornblende schists, or glaucophane schists derived therefrom. Their parent is unknown.

(10) It was shown that the chemical composition of the eclogite is similar to that of a continental basalt. The composition of garnet and pyroxene composing the eclogites is atypical with respect to eclogites occurring in areas of higher metamorphic grade. Their chemical composition, nonetheless, falls within the range of variation found in other areas.

(11) The garnet-hornblende rocks, the eclogites, and some of the glaucophane schists are related. A spatial relationship is evident in the field, and petrological investigation indicates these rocks are related by diaphthoritic processes. The retrograde metamorphism has

proceeded under conditions equivalent to the greenschist facies and perhaps the albite-epidote-amphibolite facies as well.

(12) Since the eclogites and related schists generally contain little measurable megascopic structure, it is not possible to state whether or not they conform to regional trends.

Petrogenesis

The glaucophane schists and eclogites pose many petrogenic questions. What are the conditions of metamorphism? Is the association of serpentinite with glaucophane schists in California as well as elsewhere in the world fortuitous? What is the significance of eclogites in this environment? Do the glaucophane schists represent a separate facies corresponding to distinctive conditions of temperature and pressure?

Published views concerning conditions accompanying the metamorphism are as follows:

(1) Glaucophane schists represent a facies whose development is dependent upon low to moderate temperatures, and pressures as high as those of the eclogite facies (Eskola, Barth, and Correns, 1939, p. 345, 367–8).

(2) Glaucophane schists encompass at least two subfacies, lawsonite-glaucophanite and garnet-lawsonite-glaucophane schist. These are formed by low temperature metamorphism at low and high pressure, respectively (de Roever, 1950, p. 1459–64).

(3) Metasomatic addition of sodium, calcium, aluminum, and iron from magmatic solutions originating from serpentinite is essential to development of glaucophane schists (Taliaferro, 1943, p. 159–182).

(4) Hydrothermal solutions, possibly of a sodic nature, but of unknown origin, rising along shear zones have promoted recrystallization under conditions equivalent to the greenschist and albite-epidote-amphibolite facies (Turner and Verhoogen, 1951, p. 244, 473).

In Healdsburg as elsewhere in California the schists represent a localized development of recrystallized rocks. Although foliated and linear structures indicate that deformation played some part in metamorphism, factors other than regional high pressure and moderate temperature must be invoked to account for their development.

The abundance of sodic minerals such as glaucophane, jadeite, and albite in the glaucophane schists has impressed all students of the schists; and it has been suggested that sodium has been introduced by hydrothermal solutions (Ransome, 1894; Wegmann, 1928; Huttenlocher, 1934; Suzuki, 1952). Others have noted that the schists are not particularly sodic (de Roever, 1947; Turner and Verhoogen, 1951); and still others have concluded that they could not establish that an addition of sodium had taken place (Rosenbusch, 1898; Quitzow, 1935). In California early workers including Palache and Smith believed that the composition of the recrystallized rocks does not differ significantly from that of the parent rocks. Others, including Louderback and Sharwood (1908), Davis (1918), and Taliaferro, concluded that small amounts of sodium, iron, aluminum, and water have been added to the original sediments or extrusive rock during metamorphism. These men based their conclusions on a comparison of analyses of chert and quartz-albite-glaucophane schist considered to be derived from chert. In the writer's opinion there is considerable doubt that the analyses used for the comparisons (Ransome, 1894) actually are those of recrystallized cherts.

The following observations are evidence that solutions have promoted the metamorphism at Healdsburg:

(1) The association of schists with soda-rich spilites and other metasomatically altered igneous rocks (Gealey, 1951, p. 14)

(2) Regional and local proximity of glaucophane schists to serpentinized peridotites and dunites

(3) Schists commonly veined by albite, calcite, lawsonite, pumpellyite, and glaucophane

(4) Rapid transitions in rock type over small areas or in the confines of one outcrop

In Healdsburg the most extensively developed quartz-rich schists correspond in composition to arkosic wackes of the Franciscan formation. There is no evidence that any ion has been added during metamorphism. In addition the greenstones, pumpellyite-lawsonite-glaucophane schists and eclogites have the composition of normal basalts found in the formation.

Serpentinite is present in most areas con-

taining glaucophane schists: California, New Caledonia, Japan, North Calabria, Venezuela, Corsica, Celebes, and Anglesey. The relationship between the two types of rock in all but a few of the areas mentioned does not suggest a direct genetic connection. Several workers, noting this repeated association, have suggested that magmatic solutions connected to the intrusion of peridotite were determinants in the metamorphism (Taliaferro, 1943; Suzuki, 1952; Schürmann, 1951). In California the close spatial relationship between the two suggests that contact pneumatolytic action has promoted recrystallization. Since the size of the aureole is not always in keeping with the size in the intrusion and since large bodies of schist and serpentinite occur independently of each other, it has been suggested that the amount of volatiles associated with or contained by the peridotite magma rather than the volume of the mass determines the amount of metamorphism in the intruded sediments (Taliaferro, 1943). In Healdsburg the dimensions of the serpentinite are not commensurate with the extent of metamorphism, and it is difficult to reconcile the two even if it is assumed that the magmatic fluids do not necessarily issue from the peridotite magma. It is probable that serpentinite is more abundant beneath the surface, since small outcrops can be found sufficiently far away from the main body to negate an explanation based on transportation of boulders following implacement of the main body. However, the writer believes that these observations do not account for the discrepancy between the extent of metamorphism and size of intrusive.

Rocks consisting dominantly of sodic pyroxene and almandite-pyrope-grossularite garnet have been described in severe regions containing glaucophane schists: New Caledonia (Briére, 1920); Hokkaido, Japan (Suzuki, 1930); Venezuela (Dengo, 1950); Gagerie du Brignan and Celleir, France (Briére, 1920); and California (Holway, 1904; Switzer, 1945). To workers who consider that these schists were formed under conditions of low temperature and pressure, the associated eclogites present a perplexing problem, since eclogites are generally believed to be derived under conditions of extreme pressure and temperature. Noting that the eclogites are commonly intimately associated with intrusive or tectonically transported rocks, Turner and Verhoogen (1951, p. 79–80) suggested that the Californian eclogites originated at great depths and have migrated to the upper regions of the crust. At Healdsburg there is no evidence that the eclogites have been carried up along faults or as inclusions in the peridotite magma, but the possibility cannot be discounted. An alternative explanation, suggested by Switzer (1945), is that they are products of the same metamorphism that produced the schists—under conditions of moderate temperature and pressure. This cannot be strictly true since the eclogites are not stable under conditions attending the development of the glaucophane schists from Franciscan sediments and igneous rocks. Yoder (1952) has suggested that during metamorphism the partial pressure of water has an important influence on resultant mineral assemblages. If this variable is critical, it may have governed the initial recrystallization of the Franciscan basic igneous rocks into either eclogites or glaucophane schists as well as the later alteration of the eclogites within the same period of metamorphism.

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VARIATIONS IN PLUTONS OF GRANITIC ROCKS OF THE HUNTINGTON LAKE AREA OF THE SIERRA NEVADA, CALIFORNIA

BY WARREN B. HAMILTON

ABSTRACT

The rocks of the Huntington Lake area, 160 square miles of the western slope of the central Sierra Nevada of California, are dominantly granitic. Two square miles of the area are underlain by metamorphic rocks, chiefly quartzite and marble.

The granitic rocks range from quartz diorite to alaskite and form 10 large separate and sharply bounded intrusive plutons. Each pluton varies within itself, and a series of maps has been prepared illustrating the variables of rock type, quantity and relative proportions of ferromagnesian minerals, abundance of dark inclusions, and grain size. Gradational variations within some plutons are considerable; two plutons, for example, range from quartz diorite through granodiorite to quartz monzonite. In another pluton, content of ferromagnesian minerals varies from 2 to 19 per cent.

Plagioclase and its anorthite content, total dark minerals, and the proportion of hornblende to biotite in general increase together. These interrelations are irregular, however, and quantitative generalizations are not warranted.

The abundance of ferromagnesian minerals and of dark inclusions are closely parallel. The inclusions probably are xenolithic, and some and possibly most of the mafic minerals are products of assimilation of metamorphic rocks. Most of the granitic rocks formed from the upward intrusion of mobile materials.

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schist facies. Taliaferro (1943), Read (1934) and Chenevoy (1950), who describe similarly zoned nodules occurring within gneisses, concluded that diffusion between peridotite and surrounding rocks modified their original composition.

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g. Garnet-hornblende rocks and hornblende schists with remnant pyroxene
h. Muscovite-chlorite-epidote-glaucophane schists with remnant garnet

(7) The greenstones are altered basaltic flows in which the original mineral constituents cannot be recognized. Some gave rise to pumpellyite-lawsonite-glaucophane schists.

(8) The quartz-rich schists are derived from cherts and sandstones. Metacherts are not abundant in this area; most of the siliceous rocks have been shown to be related to surrounding arkosic wackes.

(9) Garnet-lawsonite-glaucophane schists show no relationship to eclogites, garnet-hornblende schists, or glaucophane schists derived therefrom. Their parent is unknown.

(10) It was shown that the chemical composition of the eclogite is similar to that of a continental basalt. The composition of garnet and pyroxene composing the eclogites is atypical with respect to eclogites occurring in areas of higher metamorphic grade. Their chemical composition, nonetheless, falls within the range of variation found in other areas.

(11) The garnet-hornblende rocks, the eclogites, and some of the glaucophane schists are related. A spatial relationship is evident in the field, and petrological investigation indicates these rocks are related by diaphthoritic processes. The retrograde metamorphism has

proceeded under conditions equivalent to the greenschist facies and perhaps the albite-epidote-amphibolite facies as well.

(12) Since the eclogites and related schists generally contain little measurable megascopic structure, it is not possible to state whether or not they conform to regional trends.

Petrogenesis

The glaucophane schists and eclogites pose many petrogenic questions. What are the conditions of metamorphism? Is the association of serpentinite with glaucophane schists in California as well as elsewhere in the world fortuitous? What is the significance of eclogites in this environment? Do the glaucophane schists represent a separate facies corresponding to distinctive conditions of temperature and pressure?

Published views concerning conditions accompanying the metamorphism are as follows:

(1) Glaucophane schists represent a facies whose development is dependent upon low to moderate temperatures, and pressures as high as those of the eclogite facies (Eskola, Barth, and Correns, 1939, p. 345, 367–8).

(2) Glaucophane schists encompass at least two subfacies, lawsonite-glaucophanite and garnet-lawsonite-glaucophane schist. These are formed by low temperature metamorphism at low and high pressure, respectively (de Roever, 1950, p. 1459–64).

(3) Metasomatic addition of sodium, calcium, aluminum, and iron from magmatic solutions originating from serpentinite is essential to development of glaucophane schists (Taliaferro, 1943, p. 159–182).

(4) Hydrothermal solutions, possibly of a sodic nature, but of unknown origin, rising along shear zones have promoted recrystallization under conditions equivalent to the greenschist and albite-epidote-amphibolite facies (Turner and Verhoogen, 1951, p. 244, 473).

In Healdsburg as elsewhere in California the schists represent a localized development of recrystallized rocks. Although foliated and linear structures indicate that deformation played some part in metamorphism, factors other than regional high pressure and moderate temperature must be invoked to account for their development.

The abundance of sodic minerals such as glaucophane, jadeite, and albite in the glaucophane schists has impressed all students of the schists; and it has been suggested that sodium has been introduced by hydrothermal solutions (Ransome, 1894; Wegmann, 1928; Huttenlocher, 1934; Suzuki, 1952). Others have noted that the schists are not particularly sodic (de Roever, 1947; Turner and Verhoogen, 1951); and still others have concluded that they could not establish that an addition of sodium had taken place (Rosenbusch, 1898; Quitzow, 1935). In California early workers including Palache and Smith believed that the composition of the recrystallized rocks does not differ significantly from that of the parent rocks. Others, including Louderback and Sharwood (1908), Davis (1918), and Taliaferro, concluded that small amounts of sodium, iron, aluminum, and water have been added to the original sediments or extrusive rock during metamorphism. These men based their conclusions on a comparison of analyses of chert and quartz-albite-glaucophane schist considered to be derived from chert. In the writer's opinion there is considerable doubt that the analyses used for the comparisons (Ransome, 1894) actually are those of recrystallized cherts.

The following observations are evidence that solutions have promoted the metamorphism at Healdsburg:

(1) The association of schists with soda-rich spilites and other metasomatically altered igneous rocks (Gealey, 1951, p. 14)

(2) Regional and local proximity of glaucophane schists to serpentinized peridotites and dunites

(3) Schists commonly veined by albite, calcite, lawsonite, pumpellyite, and glaucophane

(4) Rapid transitions in rock type over small areas or in the confines of one outcrop

In Healdsburg the most extensively developed quartz-rich schists correspond in composition to arkosic wackes of the Franciscan formation. There is no evidence that any ion has been added during metamorphism. In addition the greenstones, pumpellyite-lawsonite-glaucophane schists and eclogites have the composition of normal basalts found in the formation.

Serpentinite is present in most areas con-

taining glaucophane schists: California, New Caledonia, Japan, North Calabria, Venezuela, Corsica, Celebes, and Anglesey. The relationship between the two types of rock in all but a few of the areas mentioned does not suggest a direct genetic connection. Several workers, noting this repeated association, have suggested that magmatic solutions connected to the intrusion of peridotite were determinants in the metamorphism (Taliaferro, 1943; Suzuki, 1952; Schürmann, 1951). In California the close spatial relationship between the two suggests that contact pneumatolytic action has promoted recrystallization. Since the size of the aureole is not always in keeping with the size in the intrusion and since large bodies of schist and serpentinite occur independently of each other, it has been suggested that the amount of volatiles associated with or contained by the peridotite magma rather than the volume of the mass determines the amount of metamorphism in the intruded sediments (Taliaferro, 1943). In Healdsburg the dimensions of the serpentinite are not commensurate with the extent of metamorphism, and it is difficult to reconcile the two even if it is assumed that the magmatic fluids do not necessarily issue from the peridotite magma. It is probable that serpentinite is more abundant beneath the surface, since small outcrops can be found sufficiently far away from the main body to negate an explanation based on transportation of boulders following implacement of the main body. However, the writer believes that these observations do not account for the discrepancy between the extent of metamorphism and size of intrusive.

Rocks consisting dominantly of sodic pyroxene and almandite-pyrope-grossularite garnet have been described in severe regions containing glaucophane schists: New Caledonia (Briére, 1920); Hokkaido, Japan (Suzuki, 1930); Venezuela (Dengo, 1950); Gagerie du Brignan and Celleir, France (Briére, 1920); and California (Holway, 1904; Switzer, 1945). To workers who consider that these schists were formed under conditions of low temperature and pressure, the associated eclogites present a perplexing problem, since eclogites are generally believed to be derived under conditions of extreme pressure and temperature. Noting that the eclogites are commonly intimately associated with intrusive or tectonically transported rocks, Turner and Verhoogen (1951, p. 79–80) suggested that the Californian eclogites originated at great depths and have migrated to the upper regions of the crust. At Healdsburg there is no evidence that the eclogites have been carried up along faults or as inclusions in the peridotite magma, but the possibility cannot be discounted. An alternative explanation, suggested by Switzer (1945), is that they are products of the same metamorphism that produced the schists—under conditions of moderate temperature and pressure. This cannot be strictly true since the eclogites are not stable under conditions attending the development of the glaucophane schists from Franciscan sediments and igneous rocks. Yoder (1952) has suggested that during metamorphism the partial pressure of water has an important influence on resultant mineral assemblages. If this variable is critical, it may have governed the initial recrystallization of the Franciscan basic igneous rocks into either eclogites or glaucophane schists as well as the later alteration of the eclogites within the same period of metamorphism.

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VARIATIONS IN PLUTONS OF GRANITIC ROCKS OF THE HUNTINGTON LAKE AREA OF THE SIERRA NEVADA, CALIFORNIA

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ABSTRACT

The rocks of the Huntington Lake area, 160 square miles of the western slope of the central Sierra Nevada of California, are dominantly granitic. Two square miles of the area are underlain by metamorphic rocks, chiefly quartzite and marble.

The granitic rocks range from quartz diorite to alaskite and form 10 large separate and sharply bounded intrusive plutons. Each pluton varies within itself, and a series of maps has been prepared illustrating the variables of rock type, quantity and relative proportions of ferromagnesian minerals, abundance of dark inclusions, and grain size. Gradational variations within some plutons are considerable; two plutons, for example, range from quartz diorite through granodiorite to quartz monzonite. In another pluton, content of ferromagnesian minerals varies from 2 to 19 per cent.

Plagioclase and its anorthite content, total dark minerals, and the proportion of hornblende to biotite in general increase together. These interrelations are irregular, however, and quantitative generalizations are not warranted.

The abundance of ferromagnesian minerals and of dark inclusions are closely parallel. The inclusions probably are xenolithic, and some and possibly most of the mafic minerals are products of assimilation of metamorphic rocks. Most of the granitic rocks formed from the upward intrusion of mobile materials.

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Introduction and Acknowledgments

The Sierra Nevada batholith of California is a composite mass formed of hundreds of separate intrusive plutons of granitic rock.

Figure 1.—Index Map of California
Huntington Lake area shown in black.

Pregranitic rocks underwent regional metamorphism of generally low to middle grade, and upon the effects of this metamorphism were superimposed those of strong contact metamorphism caused by the heat introduced with the intrusive masses. Neighboring plutons have different compositions, and single plutons vary in composition and texture within themselves. This paper presents a study of some of these variations.

The Huntington Lake area is in Fresno County in the upper-middle elevations of the western slope of the central Sierra Nevada about 50 miles northeast of Fresno (Fig. 1). The map area of 160 square miles is irregular, and most of it lies between 7000 and 10,000 feet. The area is within the new 15-minute Shuteye Peak, Kaiser Peak, Shaver Lake, and Huntington Lake quadrangle maps of the U. S. Geological Survey, but only the 30-minute Kaiser quadrangle map was available when the field work was done. Much of the area was glaciated several times during the Quaternary; large exposures of fresh glaciated rock are common (Pl. 1, fig. 1), and other large areas are covered by ground moraine.

Field work was done during the summers of 1948, 1949, and 1950. Office and laboratory facilities were provided by the Department of Geology of the University of California, Los Angeles. The writer is particularly indebted to Cordell Durrell, G. J. Neuerburg, and K. D. Watson. Helpful criticism of the final manuscript was given by Ian Campbell and F. J. Turner.

This paper deals primarily with the variations within plutons of granitic rocks and is complementary to a longer paper; for descriptions and discussions of matters here given only as summarized conclusions, the reader is referred to the other paper (Hamilton, In press.)

Bedrock mapping near this area in the Sierra includes published work by Macdonald (1941) in the foothills to the southwest and by Krauskopf (1953) to the south and southeast, and unpublished work by P. C. Bateman, K. B. Krauskopf, P. A. Lydon, and D. G. Sherlock in the crest region and east slope of the range.

Along the western edge of the central Sierra Nevada, Upper Cretaceous and Tertiary sedimentary rocks of the San Joaquin Valley overlap the Sierra bedrock complex of metasedimentary and metavolcanic rocks and intrusions of late Mesozoic granitic rocks, chiefly quartz diorite. Northeast of this foothills belt is a broad zone of granitic rocks whose average composition is granodiorite, and the Huntington Lake area is near the center of this zone. At the latitude of Huntington Lake, the broad granitic belt is bounded on the northeast by a long band, several miles wide, of metamorphic rocks, beyond which the dominant granitic type is quartz monzonite.

Metamorphic rocks underlie about 2 square miles of the Huntington Lake area, and all the large masses of metamorphic rocks are in contact with one pluton, the Kaiser Peak pluton. Of the metamorphic rocks, about 5 per cent are hornblende or biotite schists and pyroxene hornfelses, 20 per cent are marbles and calc-silicate hornfelses, and 75 per cent are quartzites.

Ten large plutons of granitic rocks make up nearly 99 per cent of the basement rocks of the map area. The rocks are unaltered and are varying shades of gray, with black grains of hornblende and biotite scattered through the

more abundant quartz and white or light-gray feldspars. Contacts between plutons are typically sharp (Pl. 1, fig. 2), and a single hand specimen containing rock of both plutons in their normal facies can be taken across many contacts. Less commonly, a smoothly gradational zone or a mixed zone as much as 50 feet wide separates adjacent plutons. Primary flow structures in the younger of two adjoining plutons are generally parallel to their contact; structures of the older pluton are truncated in some places (Pl. 4, fig. 1).

As rocks of adjacent plutons are generally conspicuously dissimilar, mapping the contacts even where exposures are poor usually causes little confusion. Only in the rare cases where the rocks on both sides of a hidden contact are similar in both composition and texture are contacts difficult or impossible to locate. Each pluton tends to be lithologically homogeneous within areas of many acres but, on a larger scale, shows gradational variations in composition and texture. Although gradational variations within a pluton can be greater than those across sharp contacts between plutons, most plutons maintain distinctve features of texture or composition.

The granitic rocks range from quartz diorite to alaskite, but four-fifths of the area is underlain by granodiorite and quartz monzonite. (Small masses of aplite, of alaskite, and of leucogabbro, each underlying only a small fraction of a square mile, will not be considered in this paper.) The granitic rock types are named on the basis of their feldspar ratios. The divisions between quartz diorite, granodiorite, quartz monzonite, and granite are made at the arbitrary ratios of plagioclase to alkali feldspar (potash feldspar, albite, and sodic oligoclase) of, respectively, 4:1, 5:3, and 3:5. Alkali feldspar is potassic in all plutons of these types except the granite of the Dinkey Lake pluton, which contains soda and potash feldspars in nearly equal quantity. Alaskite is composed of quartz, potash feldspar, and albite, with less than 1 per cent of accessory minerals. All the granitic rocks contain more than 10 per cent of quartz, and nearly all contain more than 15 per cent. Plutons are named for geographic features within or near their areas.

Plutons of Granitic Rocks

General Statement

The plutons vary from a fraction of a square mile (although the smallest ones are not treated here) to several hundred square miles, and five or six of the plutons in the map area extend beyond its borders (Fig. 2). Mineralogic compositions are given in Table 1.

The Huntington Lake pluton of medium-grained mesocratic biotite-hornblende granodiorite and quartz diorite (Pl. 2, fig. 1) underlies 11 square miles of the area.

The dikelike Helms Creek pluton is composed of mesocratic biotite-hornblende granodiorite, liberally strewn with square-tabular phenocrysts of potash feldspar. Primary flow structures in this pluton give the rock a gneissose foliation parallel to its contacts.

The Tamarack Creek pluton is composed of quartz monzonite (Pl. 1, fig. 2; Pl. 2, fig. 2), granodiorite (Pl. 3), and quartz diorite.

The Kaiser Peak pluton occupies 30 square miles and is composed of leucocratic quartz diorite, granodiorite, and quartz monzonite. Rocks of most of this pluton are texturally distinctive: much of the potash feldspar is subhedral, much of the quartz is in ellipsoidal aggregates of intergrown crystals, and crystals of ferromagnesian minerals are small and clustered (Pl. 2, fig. 3). Part of the pluton is porphyritic with large rectangular crystals of potash feldspar. The north part encloses abundant gradationally bounded masses of hybrid gneisses, and masses of dark fine-grained hybrid rocks are common in many parts of the pluton. In places, structures can be traced from schist into gneiss of increasingly granitic appearance. In this area, only this pluton contains large amounts of granitized rock.

The Mt. Givens pluton occupies 74 square miles of the map area and extends far beyond its margins. Rocks of the pluton are medium- to coarse-grained and range from leucocratic biotite quartz monzonite to mesocratic biotite-hornblende granodiorite with large euhedra of hornblende (Pl. 2, figs. 4, 8).

The Red Lake and Rodeo Meadow plutons are composed of relatively fine-grained leucocratic biotite quartz monzonite (Pl. 2, fig. 5). Although grains of other minerals average

only 1 or 2 mm long, potash feldspar commonly occurs in anhedral poikilitic crystals as much as 1 cm across; these large grains are so crowded with chadacrysts that the rocks do not appear porphyritic: rather, the potash feldspar serves as a groundmass for the other minerals. A few specimens studied are of granodiorite or granite, but these compositions are not areally consistent and seem random variations produced by the irregular distribution of late potash feldspar. Biotite occurs as scattered ragged grains.

The Sheepthief Creek pluton is composed of medium- to coarse-grained hornblende-biotite leucogranite and contains the most potassic rocks of the area (Pl. 2, fig. 6).

Eight square miles of the Dinkey Lake pluton of alaskite (Pl. 2, fig. 7) and alaskitic granite lies within the area. Gradationally bounded vugs lined concentrically with pegmatite and smoky euhedral crystals of low quartz are abundant locally. Potash and soda feldspars are subhedral to anhedral and complexly intergrown, and the rocks contain much more soda than does the granite of the Sheepthief Creek pluton. The rocks contain only minor amounts of biotite and muscovite and lack a directional fabric.

The Coyote Creek pluton is composed of alaskite similar to that of the Dinkey Lake pluton.

Contact Relations of Plutons

In the glaciated regions, contacts can be studied in minute detail on bare rock surfaces. The contacts between plutons are commonly amazingly sharp: rocks of two plutons meet and grade into each other in a zone a fraction of an inch wide (Pl. 1, fig. 2). In many places there is no apparent megascopic evidence of action, chemical or physical, exerted on one pluton by another, although enormous volumes of rock must have been displaced or incorporated by later plutons. In some cases, chemical reaction is indicated: thus, the biotite-hornblende quartz diorite of the Huntington Lake pluton was altered to biotite granodiorite near the contact with the younger and more potassic Red Lake pluton. Dikes and xenoliths of granitic rocks are rare along most contacts between plutons, though present locally (Pl. 3). Obvious displacement of one pluton by another is shown rarely, as in the truncation of flow structures of the Mt. Givens pluton by the later Rodeo Meadow pluton (Pl. 4, fig. 1);

PLATE 1.—LANDSCAPE AND INTERPLUTON CONTACT

FIGURE 1.—Southeastern part of the Huntington Lake area. Continuous exposures of fresh rock are widespread in this thoroughly glaciated part of the area.

FIGURE 2.—Contact between biotite quartz monzonite (above) of Red Lake pluton and hornblende-biotite quartz monzonite of Tamarack Creek pluton. Rock of the normal facies of each pluton meets with a contact zone a tenth of an inch wide. Scale is 6 inches long.

PLATE 2.—HAND SPECIMENS OF GRANITIC ROCKS. ×⅔

FIGURE 1.—Biotite-hornblende quartz diorite, Huntington Lake pluton, north part.

FIGURE 2.—Biotite-hornblende quartz monzonite, Tamarack Creek pluton, east part. A small fine-grained hornblendic inclusion is present at the lower left.

FIGURE 3.—Hornblende-biotite quartz monzonite, Kaiser Peak pluton, central part. Most mafic minerals are in clusters of small grains.

FIGURE 4.—Biotite-hornblende granodiorite, Mt. Givens pluton, northeast part. Mafic minerals are large and euhedral. A fine-grained inclusion is present at the right edge.

FIGURE 5.—Biotite quartz monzonite, Red Lake pluton, northern part. The rock is finer-grained than that of most of the other plutons.

FIGURE 6.—Hornblende-biotite granite, Sheepthief Creek pluton.

FIGURE 7.—Alaskite, Dinkey Lake pluton, northern part. Quartz is smoky gray brown and photographs dark; this specimen has only a few flecks of biotite.

FIGURE 8.—Specimen across contact, showing assimilation of pyroxene hornfels by granodiorite of Mt. Givens pluton. Near the granitic contact, finely granular pyroxene (gray) was reconstituted to large euhedral poikilitic hornblende (black). At the contact, felsic components of the hornfels were dissolved, and the xenocrystic hornblendes floated away unoriented.

FIGURE 1

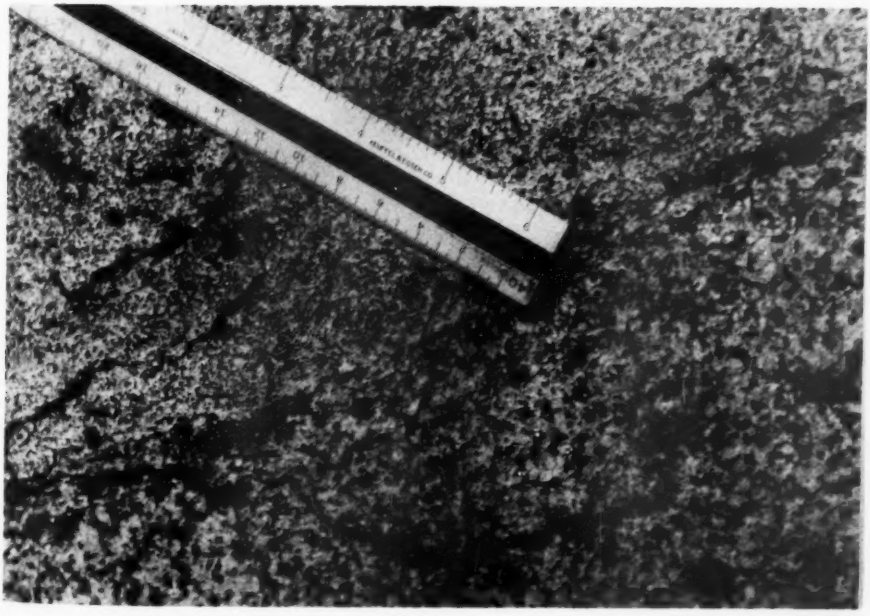
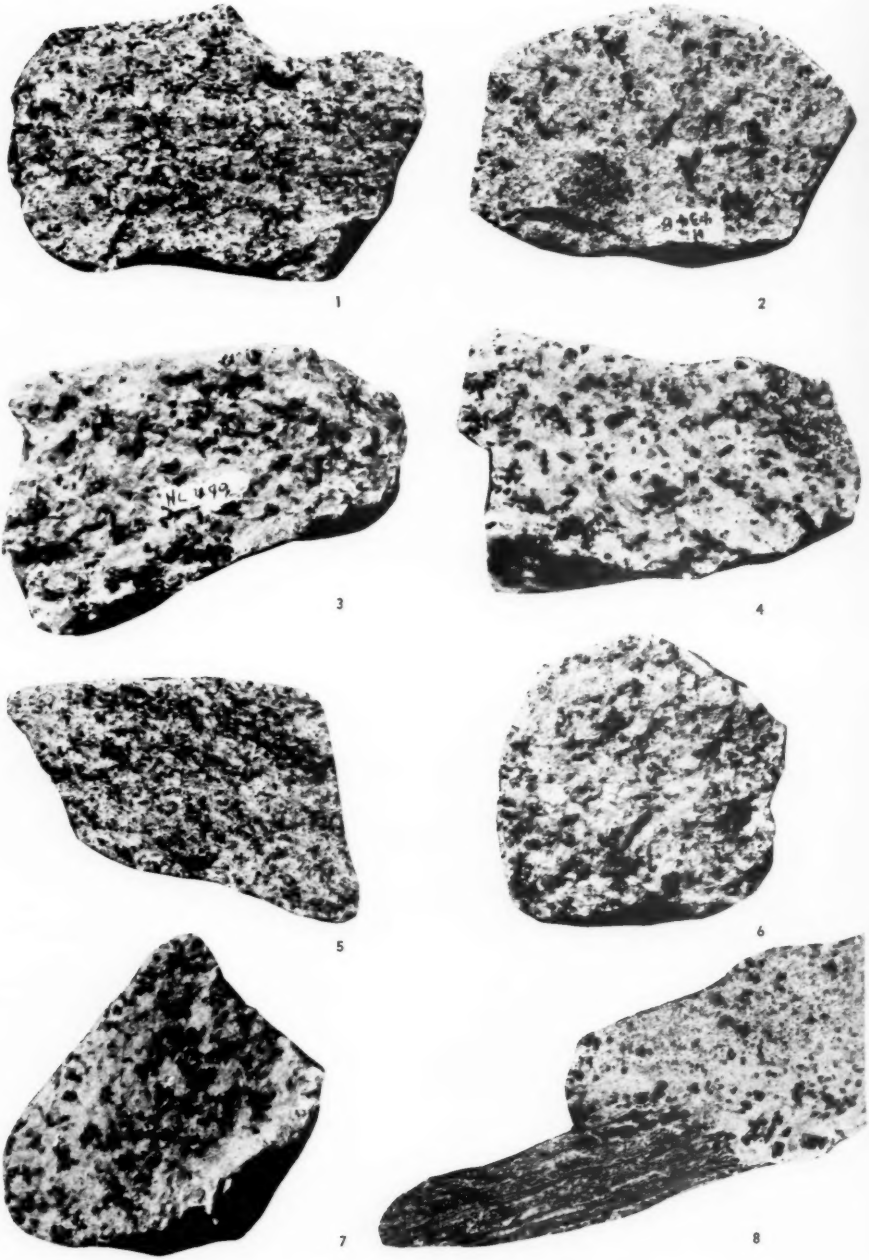


FIGURE 2
LANDSCAPE AND INTERPLUTON CONTACT



HAND SPECIMENS OF GRANITIC ROCKS
X 2/3

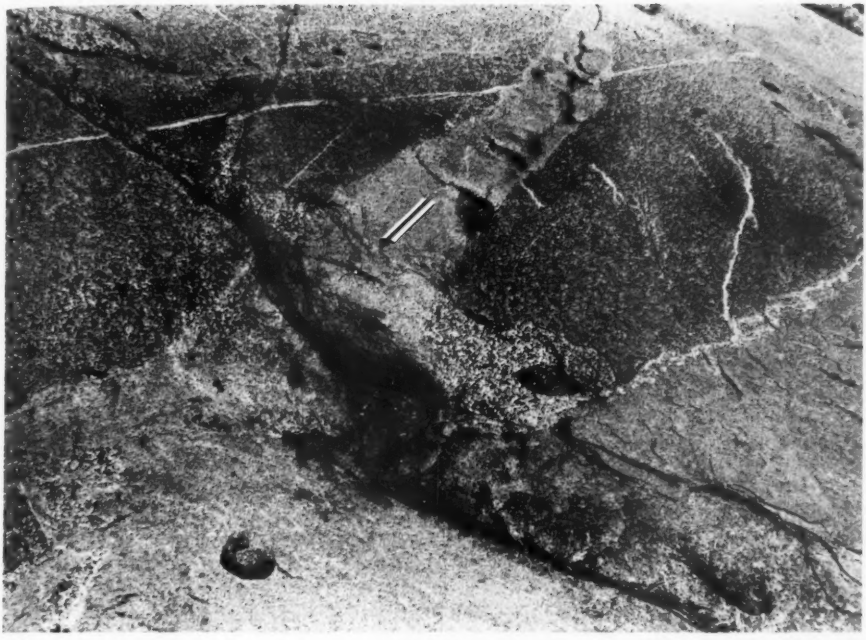


FIGURE 1

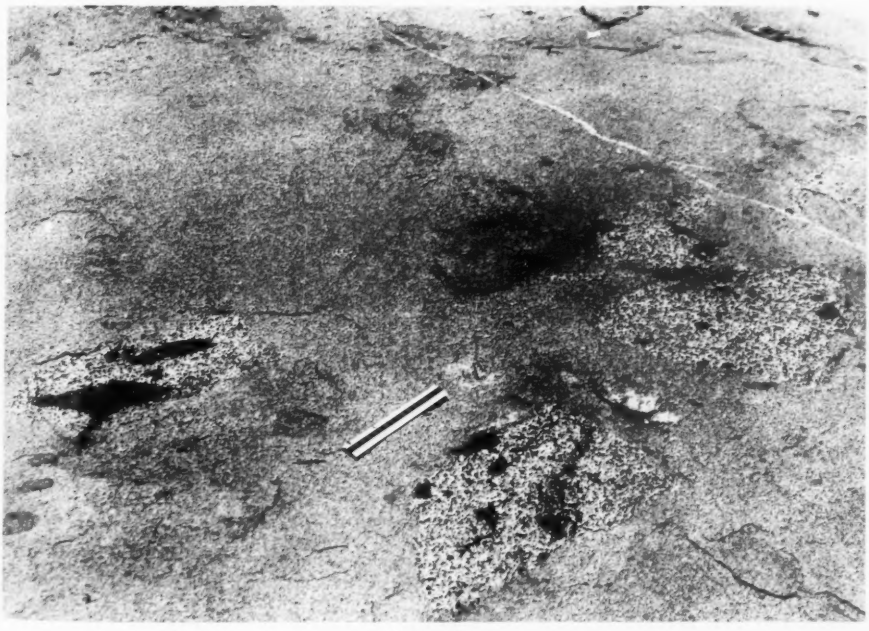


FIGURE 2

INTRUSIVE RELATIONSHIPS BETWEEN QUARTZ MONZONITE OF RED LAKE PLUTON, AND GRANODIORITE OF TAMARACK CREEK PLUTON

FIGURE 1

FIGURE 2

FIGURE 3

FEATURES SHOWING DISPLACEMENT BY INTRUSIVE PLUTONS, AND THE FORMATION OF DARK INCLUSIONS

most of the contact between these two plutons resembles that in Figure 2 of Plate 1.

In probable order of decreasing age the various plutons may be grouped as follows:

(1) Western or older group: Tamarack Creek, Huntington Lake, Sheepthief Creek, Kaiser Peak; relative order of emplacement unknown.

(2) Eastern or younger group: Mt. Givens, Red Lake and Rodeo Meadow, Dinkey Lake and Coyote Creek, Helms Creek.

Mineralogy

General Statement

The approximate mineralogic composition of the granitic rocks is shown on Table 1. The figures give minimum and maximum volumetric percentages, slightly generalized to omit extreme variants of minor distribution, and are based on visual estimates made by comparison with patterns of known areal densities. Minor accessory minerals are not included. The per cent of plagioclase is shown under the most abundant type for the pluton represented, and other types of plagioclase present are indicated by X's.

The variations in these figures for the rocks of any one pluton reflect the variations of the pluton. Gradual variations within single plutons are in many cases of greater magnitude than are abrupt changes between plutons.

Quartz

Anhedral quartz is present in all the granitic rocks and varies in quantity from 10 to 35 per cent. In all rocks but those of the Kaiser Peak pluton it occurs as highly irregular grains, many of which are discontinuous in the plane of a thin section. The size of the grains in general increases with increasing quartz content. Much of the quartz of the Kaiser Peak pluton is in ellipsoidal aggregates a few millimeters long of intergrown anhedral crystals. Quartz is gray in hand specimen in all rocks except the alaskites. In the alaskites, the quartz is smoky gray brown, as is the euhedral low quartz of the abundant gradationally bounded pegmatitic vugs of the alaskite. In the granite of the Dinkey Lake pluton, the quartz is a lighter smoky gray.

The quartz of the southeastern quarter of the area—the Dinkey Lake, Coyote Creek, Red Lake, Rodeo Meadow, and Helms Creek plutons and the southern part of the Mt. Givens pluton—shows little or no mosaic or undulatory extinction. The quartz of the rest of the area shows marked mosaic and undulatory extinction.

Potash Feldspar

Potash feldspar is present in all the granitic rocks and varies in amount from 2 to 70 per cent. Most of the potash feldspar except for

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Plate 3.—INTRUSIVE RELATIONSHIPS BETWEEN QUARTZ MONZONITE OF RED LAKE PLUTON AND GRANODIORITE OF TAMARACK CREEK PLUTON

Figure 1.—Dike of fine-grained quartz monzonite cutting granodiorite. Scale is 6 inches long.
Figure 2.—Xenoliths of granodiorite with dark inclusions, in quartz monzonite.

Plate 4.—FEATURES SHOWING DISPLACEMENT BY INTRUSIVE PLUTONS, AND THE FORMATION OF DARK INCLUSIONS

Figure 1.—Contact between quartz monzonites of Mt. Givens pluton (left) and Rodeo Meadow pluton (right), separated by layered amphibolitic rock. Flow structures of the Mt. Givens pluton, shown by schlieren, are truncated against a zone a few inches wide, just left of the amphibolite, of remobilized massive rock. Flow structures in the Rodeo Meadow pluton, not apparent in the picture, are parallel to the amphibolite. The amphibolite is probably a recrystallized sheared rock. Scale is 6 inches long.

Figure 2.—Contorted pyroxene hornfels, 40 feet from contact with Mt. Givens pluton. The structures and mineralogy indicate strong deformation at high temperatures, presumably caused by the intruding pluton; however, the final contact was passively established (Pl. 2, fig. 8). Scale is 6 inches long.

Figure 3.—Dark inclusions arrested in process of formation as xenoliths in porphyritic facies of Mt. Givens pluton. Dark fine-grained metamorphic rock (above hammer) was broken into numerous small inclusions, the mineralogy and texture of which were altered by reaction with the quartz monzonite.

that of the Huntington Lake pluton appears patchy under crossed Nicols with patches of grid-twinned "microcline" in nontwinned "orthoclase." (Goldsmith and Laves, 1954, found that natural potash feldspars have within "single" crystals all degrees of triclinicity between orthoclase and microcline: "K-feldspars may be composed of triclinic units of any size, as expressed by macroscopic through submicroscopic twinning."—p. 116). Most of the potash feldspar is microperthitic, and both perthite and the completeness of grid twinning show an irregular increase toward the more silicic and alkali feldspar-rich rocks. Potash feldspar is white in fresh specimens of most rocks, very pale orange in the alaskites, and very pale lavender in part of the Kaiser Peak pluton.

Some grains of potash feldspar are anhedral, and others are subhedral in the granites and alaskites and in the Kaiser Peak pluton. In most other rocks in which it is present in important quantity, potash feldspar is in large anhedral grains that poikilitically enclose all other minerals. Many of these poikilitic crystals attain dimensions of more than 1 cm. Rectangular phenocrysts of potash feldspar as much as 2 inches long abound in the northwest part of the Kaiser Peak pluton. Square-tabular phenocrysts with an average diameter of five-eighths of an inch are abundant in the Helms Creek pluton and in the Mt. Givens pluton

TABLE 1.—MINERALOGIC COMPOSITION OF GRANITIC ROCKS OF THE HUNTINGTON LAKE AREA, SHOWING RANGE IN VOLUMETRIC PER CENT

Pluton and rock type	Mineral												
			Plagioclase feldspar					Accessory minerals					
	Quartz	Potash feldspar	An 0-10	An 10-20	An 20-30	An 30-40	An 40-50	Total accessories	Hornblende	Biotite	Muscovite	Number of thin sections
Alaskite of Dinkey Lake pluton, and Coyote Creek pluton	25–35	35–45	20–35	X				½–1		¼–½	¼–½	7
Granite of Dinkey Lake pluton	20–25	40–50	X	25–35				1–3		½–2	½–1	3
Sheepthief Creek pluton (granite)	15–25	50–70		X	10–30			2–5	½–2	2–4		5
Rodeo Meadow pluton (quartz monzonite)	20–25	30–40			35–45			3–5	tr	3–5		3
Red Lake pluton (quartz monzonite)	20–25	25–50			X	25–50		2–7	tr	2–7		14
Mt. Givens pluton (quartz monzonite, granodiorite)	15–25	15–50			X	25–55	X	2–19	tr-15	2–7		46
Kaiser Peak pluton (quartz monzonite, granodiorite, quartz diorite)	20–35	10–40			X	25–50		3–10	tr-5	3–6		45
Tamarack Creek pluton (quartz monzonite, granodiorite, quartz diorite)	15–20	15–35			X	40–60	X	7–10	3–7	3–4		3
Helms Creek pluton (granodiorite)	15–20	15–25				45–55		10–15	4–10	5–9		5
Huntington Lake pluton (granodiorite and quartz diorite)	10–20	2–30				X	45–60	7–20	3–14	4–7		14

near the Coyote Creek pluton. In many specimens, potash feldspar appears to have replaced plagioclase. The reaction, probably deuteric alteration by late potassic liquid, varies from slight embayment to complete replacement of plagioclase enclosed or bordered by potash feldspar.

Plagioclase

Plagioclase is present (10–70 per cent) in all the granitic rocks. Soda-lime varieties (An > 20) occur in all but the alaskite and related granite, which contain soda feldspar (An < 20). Plagioclase crystals are commonly subhedral, tabular parallel to (010), and from 1 to 5 mm in average maximum dimension. Plagioclase grains are smaller than those of potash feldspar in all rocks in which potash feldspar is abundant. Plagioclase in fresh specimens ranges from light gray in the quartz diorite of the Huntington Lake pluton to nearly white in most of the other plutons. The albite of the alaskites is very pale orange.

Plagioclase varies from about An_5 to An_{50}, and its albite content irregularly correlates with silica content of the rocks. Plagioclase in all rocks is normally zoned, with a common range of anorthite content in single crystals of 10 or 20 per cent. Crystals in most rocks have large cores, commonly showing slight oscillatory zoning but varying little in composition. Outside of these cores are narrow zones of rapid gradation—oscillatory in many places—to sodic rims which are fairly broad and uniform; the outer zones are not present on many crystals. Many crystals contain several dozen oscillations of composition. "Unconformities" in zoning are common; some are abrupt changes in composition, but many are also surfaces of alteration and embayment.

Biotite

Biotite is present in all the granitic rocks and varies from a trace to 9 per cent. Crystals are commonly subhedral books with well-developed basal pinacoids but lacking other faces. Grains average about half a millimeter in length in the alaskitic plutons, about 1 mm in the Red Lake and Rodeo Meadow plutons, and about 2 mm in most of the other rocks. All the biotite has similar optical properties with a pleochroism of X pale yellow brown, Y and Z dark olive brown.

Hornblende

Hornblende is present in most of the granitic rocks and varies from a trace to 15 per cent. Crystals are commonly prismatic with well-developed prism faces and without terminations. The quality of crystal outline varies with the degree of aggregation of the crystals; in the Mt. Givens pluton, crystals of the mafic minerals are distinct and well formed, whereas in the Kaiser Peak pluton they are clustered and poorly formed. The size of hornblende crystals increases with the hornblende content. The hornblende of both granitic and metamorphic rocks is the common green variety, black in hand specimen, with pleochroism X pale brown, Y olive green, and Z green.

Muscovite

Muscovite is present in the alaskitic plutons, where most of it is in small ragged anhedra.

Minor Accessory Minerals

Magnetite and sphene are the most abundant minor accessories; magnetite is present in all the granitic rocks, and sphene in all except alaskites. Magnetite occurs in equidimensional grains, in many places bordering or included in biotite or hornblende. Euhedral wedges of sphene 7 mm long occur in the darkest parts of the Mt. Givens pluton; in other places sphene occurs in tiny barrel-shaped crystals. The latter habit is a characteristic of the Kaiser Peak pluton and is similar to that of the sphene of the metamorphic rocks. Anhedral wisps of sphene, apparently by-products of the replacement of biotite by potash feldspar, were observed in a few slides. Minute euhedral prisms of apatite and zircon are present in all the granitic rocks, and euhedral crystals of zoned allanite are present in small quantity in all the rocks except those of the alaskitic plutons. Red garnet is present in the alaskites.

Variations in Granitic Rocks

Variation Maps

A series of variation maps (Figs. 2–7) has been prepared to illustrate some of the variables within plutons of granitic rocks. The variables plotted are rock type (Fig. 2), quantity (Fig. 3) and proportions (Fig. 4) of ferromagnesian minerals, abundance of dark inclusions (Fig. 5) and grain size (Fig. 6).

Most contacts between plutons and between metamorphic and granitic rocks are sharp and were mapped in the field. Within plutons, gradational changes are shown by patterns on the variation maps, and the exact locations and shapes of contacts between patterns are arbitrary. The variation maps were compiled by laboratory study of hand specimens, thin sections, and field notes. Location of mapped contacts and of hand specimens is shown in Figure 7. Thin sections from 145 of these specimens were studied. The reliability of the

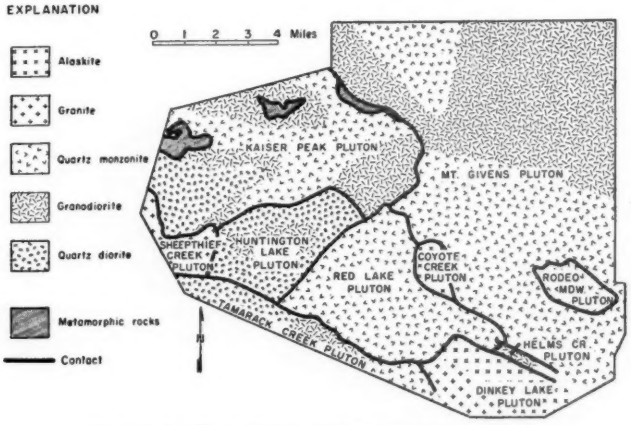

Figure 2.—Rock Types of Huntington Lake Area

Contacts between plutons and between granitic and metamorphic rocks are indicated by heavy lines on this and other variation maps. Within plutons, rock types are indicated by patterns.

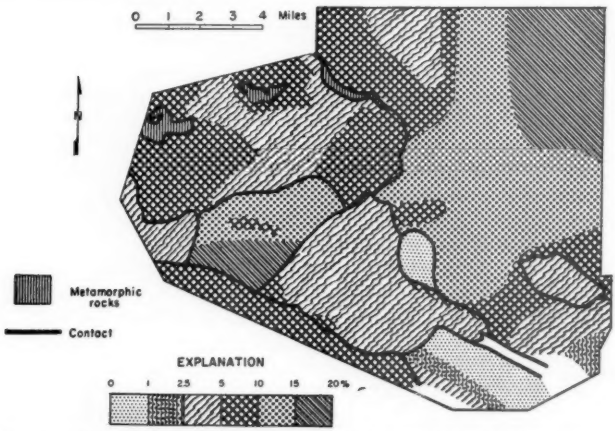

Figure 3.—Quantity of Ferromagnesian Minerals in Granitic Rocks

Patterns indicate the total volumetric per cent of hornblende, biotite, and muscovite.

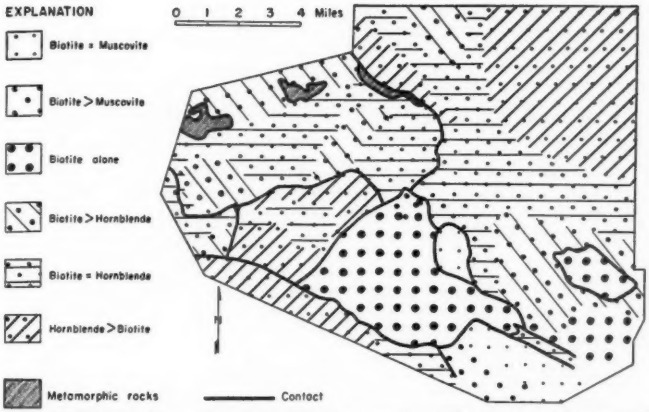

FIGURE 4.—RELATIVE PROPORTIONS OF FERROMAGNESIAN MINERALS IN GRANITIC ROCKS

The symbol = is used where the proportion is between 3:2 and 2:3, and the symbol > where the proportion is greater than 3:2.

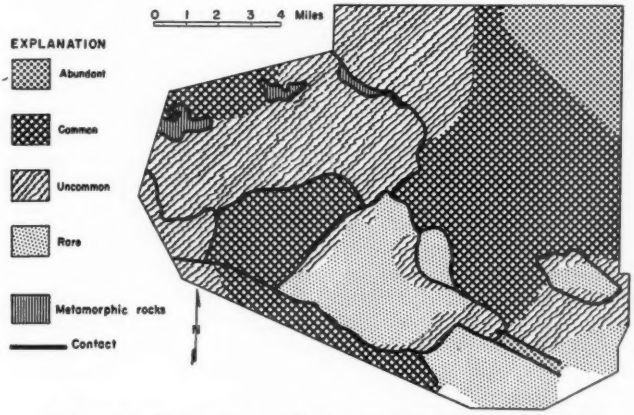

FIGURE 5.—ABUNDANCE OF DARK INCLUSIONS IN GRANITIC ROCKS

Where the abundant pattern is used, several inclusions per square yard of outcrop are present; where the rare pattern appears, inclusions are very scarce.

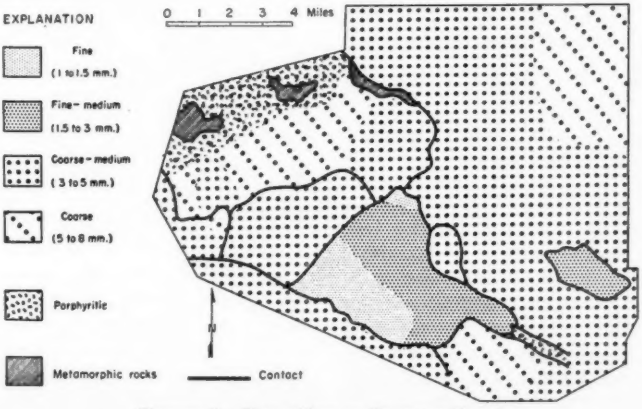

FIGURE 6.—GRAIN SIZE OF GRANITIC ROCKS

The porphyritic rocks contain phenocrysts of potash feldspar.

pattern distributions varies with spacing of of the specimens. Another factor influencing the accuracy of isopleths is the possible variability of the rocks within small areas, but

Of the variables plotted, rock type is most subject to mislocation through sampling deficiencies. Rock type was determined almost entirely from thin sections—hence from only

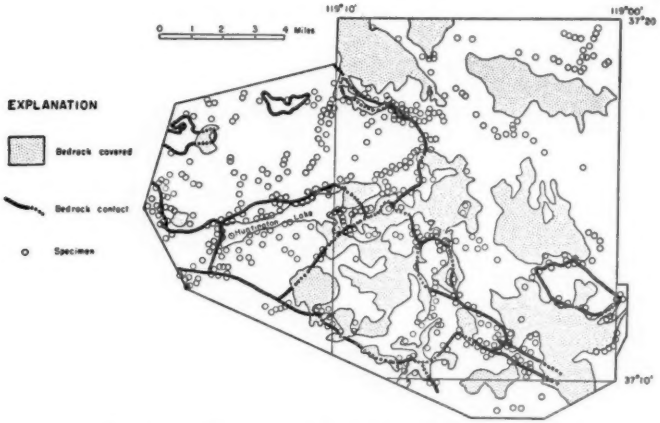

FIGURE 7.—QUALITY OF CONTROL FOR VARIATION MAPS

Exposed contacts between plutons were mapped in the field, and variation maps were constructed from notes and specimens. Sample locations are generalized in areas of dense sampling.

most of the plutons are uniform over areas large enough to minimize this difficulty. Much of the eastern two-thirds of the area is covered by surficial debris, most of which is ground moraine, and these covered areas are also shown in Figure 7.

Rock Type

The distribution of rock types is shown in Figure 2. The relative areal abundances of the granitic rock types is approximately as follows:

	Per cent
alaskite	5
granite	4
quartz monzonite	47
granodiorite	33
quartz diorite	11

The rock type ranges widely within many of the plutons. Rocks range from quartz diorite through granodiorite to quartz monzonite in the Kaiser Peak and Tamarack Creek plutons, from quartz diorite to granodiorite in the Huntington Lake pluton, from granodiorite to quartz monzonite in the Mt. Givens pluton, and from granite to alaskite in the Dinkey Lake pluton.

half as many points as the other variables. The irregular distribution of late potash feldspar permits adjacent hand specimens to be of different rock types; nevertheless, the areal consistency of the determinations shows the variations to be in general as shown.

The cause of variations of rock types may be the same as the cause of variations between plutons, but neither cause is understood. Perhaps parental materials were varied and never completely mixed, and introduced materials were distributed irregularly.

Abundance and Relative Proportions of Ferromagnesian Minerals

The abundance and relative proportions of ferromagnesian minerals in the granitic rocks are shown in Figures 3 and 4. The abundance of ferromagnesian minerals varies from less than 1 per cent to 20 per cent and is related to rock type. As soda-lime feldspar increases within a pluton, so in general the total mafic mineral content increases. A given rock type does not contain a constant amount of mafic minerals, however: the granodiorite of the Mt. Givens pluton, for example, contains much

more hornblende and biotite than does the quartz diorite of the Kaiser Peak pluton.

The relative proportions of ferromagnesian minerals to each other vary with the rock types and the total amount of dark minerals. In general, the ratio of hornblende to biotite increases with the content of mafic minerals and of soda-lime feldspar. This generalization is more valid within a pluton than between plutons: although the Red Lake and Sheepthief Creek plutons, for example, have about the same content of mafic minerals, the quartz monzonite of the Red Lake pluton contains only biotite, whereas the granite of the Sheepthief Creek pluton contains about as much hornblende as biotite.

The increase of hornblende in the Mt. Givens pluton toward the septum in the north-central part of the area is probably due to assimilation of pyroxene hornfels. Within a few inches of the contact, hornblende crystals were produced in the hornfels, growing poikiloblastically by replacing clinopyroxene grains, with hornblende prisms elongate in the layers of the hornfels. At the contact, which is commonly sharp but irregular, hornblende crystals abruptly lost orientation as the quartz and feldspar of the hornfels were dissolved by the granodiorite (Pl. 2, fig. 8). The conversion of clinopyroxene to hornblende and the solution of quartz and feldspars conform with the order of Bowen's reaction series. In the granodiorite at the contact, hornblende xenocrysts contain many chadacrysts of felsic minerals from the hornfels, but the abundance of chadacrysts decreases rapidly, and a few yards from the contact the hornblende crystals have no chadacrysts. Hornblende xenocrysts were formed poikiloblastically in hornfels, incorporated into the granodiorite, and there cleared of chadacrysts; such xenocrysts appear to be identical with the hornblende crystals throughout the pluton. Most of the hornblende of the pluton may be the result of such assimilation as xenocrysts of metamorphic material. If all the hornblende in the granodiorite near the septum had such an origin in pyroxene hornfels, then about one-fifth of the volume of that granodiorite represents assimilated material.

Similar assimilation was observed outside the map area at the contact between the Mt. Givens pluton and metavolcanic rocks to the east, so that the increase in hornblende in the northeast part of the map area may also be due to assimilation.

Abundance of Dark Inclusions

Figure 5 shows the abundance of dark inclusions in the granitic rocks. Such inclusions have been the subject of much speculation. Darker and finer-grained than the enclosing granitic material and sharply bounded against it, the ellipsoidal inclusions have common maximum dimensions of a few inches to a foot (Pl. 2, fig. 2; Pl. 3; Pl. 4, fig. 1). Often given names of genetic implication (*e.g.*, "autolith", "basic segregation"), similar inclusions have been variously and conflictingly interpreted as having hypidiomorphic granular, xenomorphic granular, and crystalloblastic textures. Although Pabst (1928) concluded that the Sierran inclusions are autoliths, a satisfactory explanation of an autolithic origin has not yet been made, and the writer considers most of the inclusions to be reconstituted xenoliths.

The inclusions are commonly triaxial with parallel orientations, and in general the better the parallelism, the more elongate the inclusions. The alignment shows differential movement within the granitic intrusives. The inclusions are gray to black and commonly have a grain size between 0.1 and 1 mm. Plagioclase makes up more than half of most inclusions. Hornblende is the most abundant ferromagnesian mineral, but biotite is present in nearly all inclusions and is the only dark mineral in some. The ratio of hornblende to biotite in the inclusions is generally higher than the ratio in the enclosing granitic rock. Potash feldspar commonly forms large late poikilitic anhedral crystals, and quartz is in small irregular grains. Plagioclase, hornblende, and biotite are commonly anhedral and butt against and enclose each other, suggesting crystallization in the solid state. The inclusions vary greatly in grain size, composition, and texture; even in a small area of a given pluton, many different types of inclusions are commonly present.

In a few locations, inclusions showing many of the textural and compositional features of the inclusions of doubtful origin can be seen arrested in the process of splitting as xenoliths

from metamorphic rocks (Pl. 4, fig. 3). In other places, obvious xenoliths of amphibolites occur with the more abundant inclusions of dubious origin. Some of the inclusions are certainly hybridized xenoliths; no other origin for the others has been proved, and most of them may have originated as xenoliths.

The abundance of dark inclusions (Fig. 5) is strikingly parallel to that of ferromagnesian minerals (Fig. 3). The abundance of inclusions varies from several per cent of the enclosing rock (as in the northeastern part of the Mt. Givens pluton) to perhaps one small inclusion per acre (in the alaskites). The close relation between abundances of dark inclusions and dark minerals is perhaps to be expected, whatever the origin of each. If most of the inclusions have a hybrid origin, then the dark minerals might also be metamorphic in origin: a possibility previously suggested on the basis of contact assimilation reactions for the hornblende of the Mt. Givens pluton.

Grain Size

The grain size of the granitic rocks ranges greatly (Fig. 6). About five-eighths of the rocks are of coarse-medium grain size, one-fourth are coarse, and one-eighth are fine or fine-medium.

The grain size of the rocks of the eastern group of plutons can be explained in conventional terms, although the explanations are not necessarily correct. The Mt. Givens pluton increases in grain size inward (northeast). The grain size of the Red Lake pluton is in general finer against the plutons of the western group than against the Mt. Givens pluton, perhaps indicating that the Mt. Givens pluton, though solid, was hotter than the western plutons at the time of the Red Lake intrusion. The Rodeo Meadow pluton may be relatively fine because of the small size and attendant relatively fast cooling of the pluton. The Coyote Creek and Dinkey Lake plutons are coarse because of high volatile content, clearly shown by the compositions of the rocks and their abundant pegmatites.

The porphyritic rocks are of two types, probably of different origins. In both types, the phenocrysts are of potash feldspar and are poikilitic, but those of the Kaiser Peak pluton are large rectangular crystals, whereas those in the Helms Creek and Mt. Givens plutons are square-tabular crystals. The porphyritic rocks of the Kaiser Peak pluton occur along a high ridge that exposes the highest remaining part of the pluton, and it might be suggested accordingly that the porphyritic rocks resulted from the flotation of feldspars or the concentration upward of residual volatiles. If this were true, then the porphyritic rocks should be higher in potash feldspar than the nonporphyritic rocks topographically below them, but instead the porphyritic rocks are dominantly granodiorite whereas the rocks below are dominantly quartz monzonite. Similar large crystals of potash feldspar are found in a porphyroblastic relation in many of the small masses of granitized metasediments. The "phenocrysts" may be liberated porphyroblasts from such metamorphic rocks, an explanation which is consistent with the fact that the porphyritic rocks occur only in that part of the pluton where granitized metasediments are abundant.

The phenocrysts in the Mt. Givens and Helms Creek plutons are developed only near alaskite contacts. In the Mt. Givens pluton, the phenocrysts decrease away from the contact; in the dikelike Helms Creek intrusion, the phenocrysts are uniformly distributed. In both cases, the potash represented by the phenocrysts was probably obtained from the alaskites, but the mechanisms of the processes are not understood; in one case, the porphyritic rock is probably older, and in the other probably younger, than the alaskite with which it is in contact.

Emplacement of Plutons

The granitic rocks of the Sierra Nevada form an exposed mass 300 miles by as much as 70 miles, and this great expanse of granitic rock occupies space once occupied by metamorphic rock. The means of emplacement of the granitic rocks presents a complex problem, for which diverse and conflicting explanations have been attempted.

The following are among the features indicating formation by intrusion rather than formation in place by a process of granitization:

(1) Metamorphic wall rocks were subjected to intense contact metamorphism, showing

steep thermal gradients outward from the plutons, demonstrating that heat was introduced by the plutons.

(2) Contacts are discordant and sharp, in many places knife sharp, whether separating rocks of similar or grossly different compositions, yet many individual plutons are broadly uniform. (Exceptions are numerous in the gabbros and mafic quartz diorites of the Sierra foothills, but not in the Huntington Lake area.)

(3) Pre-intrusion regional metamorphism of the Sierran geosynclinal sediments and volcanics generally reached only low to medium grades, and gneiss and migmatite are uncommon. There is little development of rocks texturally intermediate between granitic and metamorphic rocks. (Within the Huntington Lake area, most exceptions are in the Kaiser Peak pluton.)

(4) Features such as the relative uniformity of the granitic rocks over considerable areas, the gradual variations within plutons, and the usual independence of dark inclusions (xenoliths?) and contacts indicate that the intrusive material was mobile enough to permit mixing of large volumes.

(5) Primary flow structures marked by parallelism of dark inclusions and of platy and prismatic minerals indicate that the plutons moved differentially within themselves without cataclasis. The structures are parallel to contacts rather than to wall-rock structures, although contacts and wall-rock structures may be parallel. Structures are shown on the map accompanying another paper (Hamilton, In press).

The flow structures are marked by parallelism of dark inclusions and of platy and prismatic minerals, generally with a planar orientation and a weaker down-dip lineation. Schlieren are present locally. Assuming that lineation is parallel to the direction of flow, the flow structures demonstrate that each of the plutons moved upward, expanding laterally, with the amount of upward movement increasing inward. The flow structures record movements made by the magmas when they were mobile but nearly solid.

The granitic masses moved generally upward, so that most of the granitic material must have come from lower levels. Most of the space now occupied by granitic rocks must have been gained by the physical displacement of older granitic and metamorphic rocks. There is much doubt about the processes by which this displacement was accomplished.

Had forceful injection been important, widespread marginal brecciation, thrusting, and peripheral shearing should have occurred near contacts between granitic and metamorphic rocks and between granitic plutons, but such features are uncommon. (Studies of joints do not appear relevant to determining the means of emplacement of individual plutons, as major joints sets continue without interruption across pluton contacts.) Extreme deformation of metamorphic rocks near the contact with the Mt. Givens pluton occurred locally (Pl. 4, fig. 2), but the actual contacts indicate passive assimilation and crystallization (Pl. 2, fig. 8); also, straight dikes from the pluton crosscut the contortions. Perhaps an early phase of forceful injection preceded the final passive phase.

The contacts between most plutons present no apparent evidence of the means of their formation. Most exposed contacts are sharp enough to be covered by one hand (Pl. 1, fig. 2); dislocation (Pl. 4, fig. 1) or injection (Pl. 3) is rarely shown. Commonly, rocks on opposing sides continue to the contact with little or no change in texture or composition from their normal character. The final stages of crystallization and the achievement of the final contacts must generally have been passive. The general absence of stoped blocks and of contact alterations makes the process a mystery.

The formation of granitic rocks by processes of plutonic metamorphism, together with regional development of gneisses and migmatites, is indicated in many areas in the Canadian Shield and in some parts of the Nevadan belt, *e.g.*, the Shuswap terrane (Cairnes, 1940) and parts of the Idaho batholith region (Hamilton, 1953). By contrast, the granitic rocks of the Sierra Nevada are sharply bounded against contact-metamorphosed rocks and are grossly different from most rocks of the plutonically metamorphosed complexes. Perhaps the different associations represent different levels of exposure of genetically related processes.

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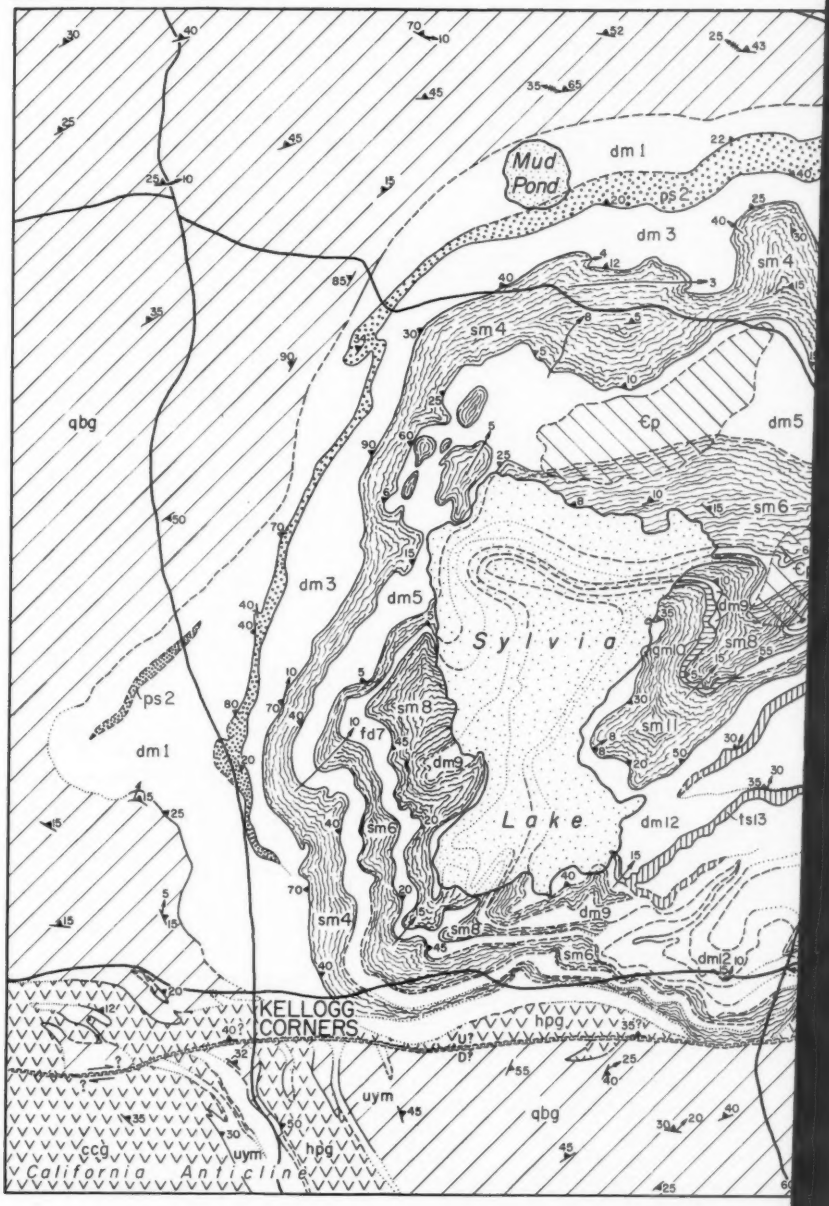
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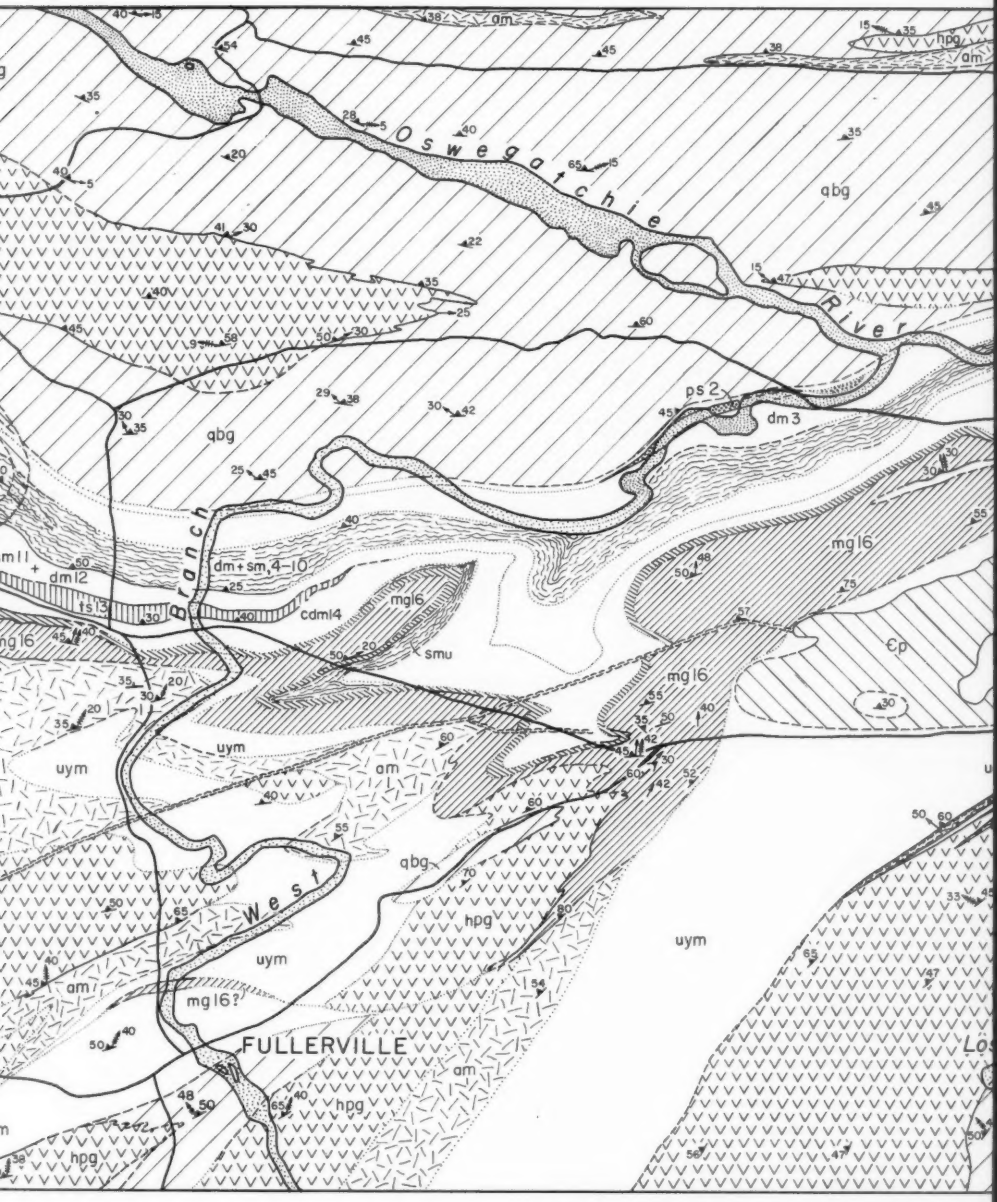

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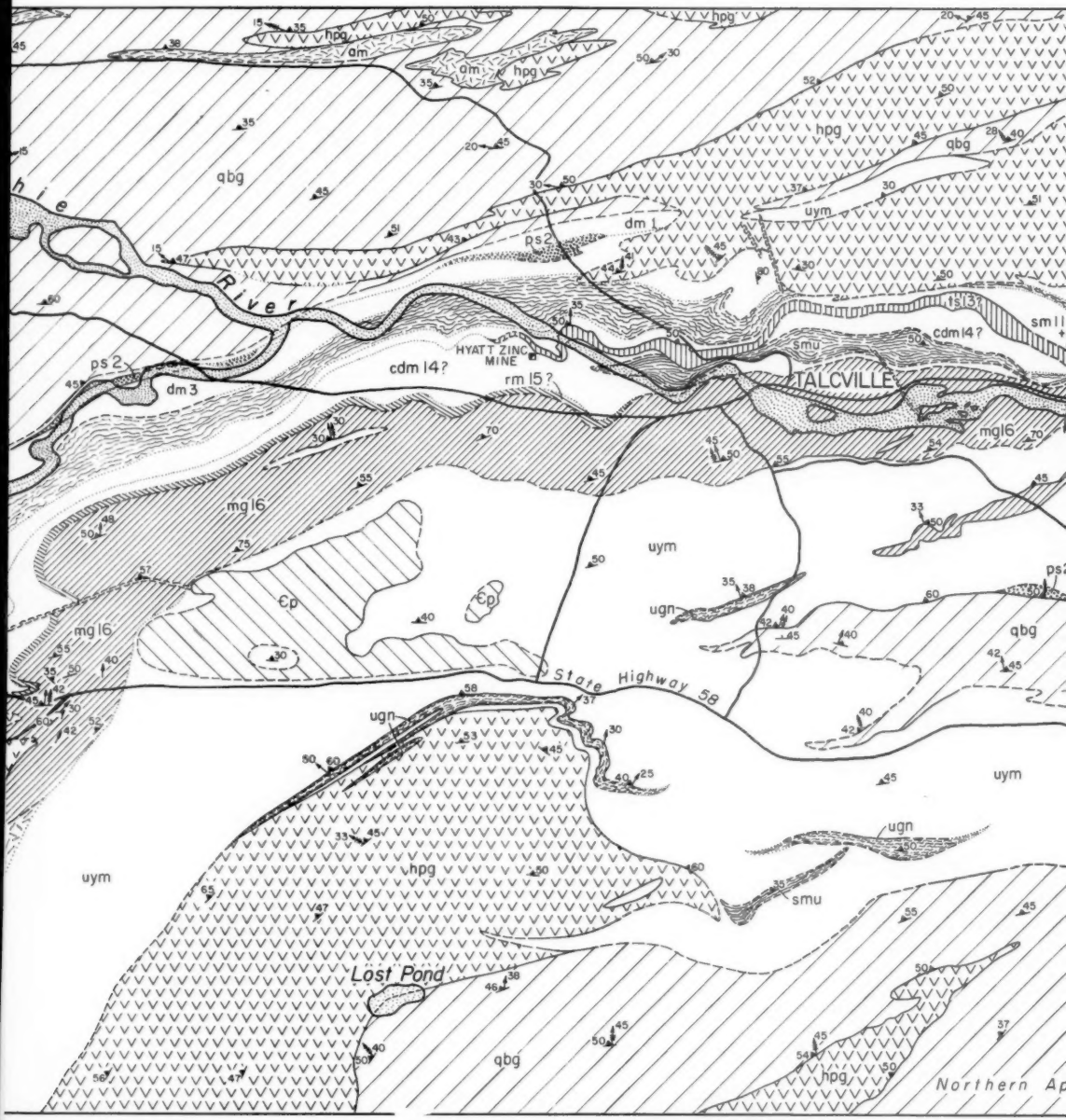

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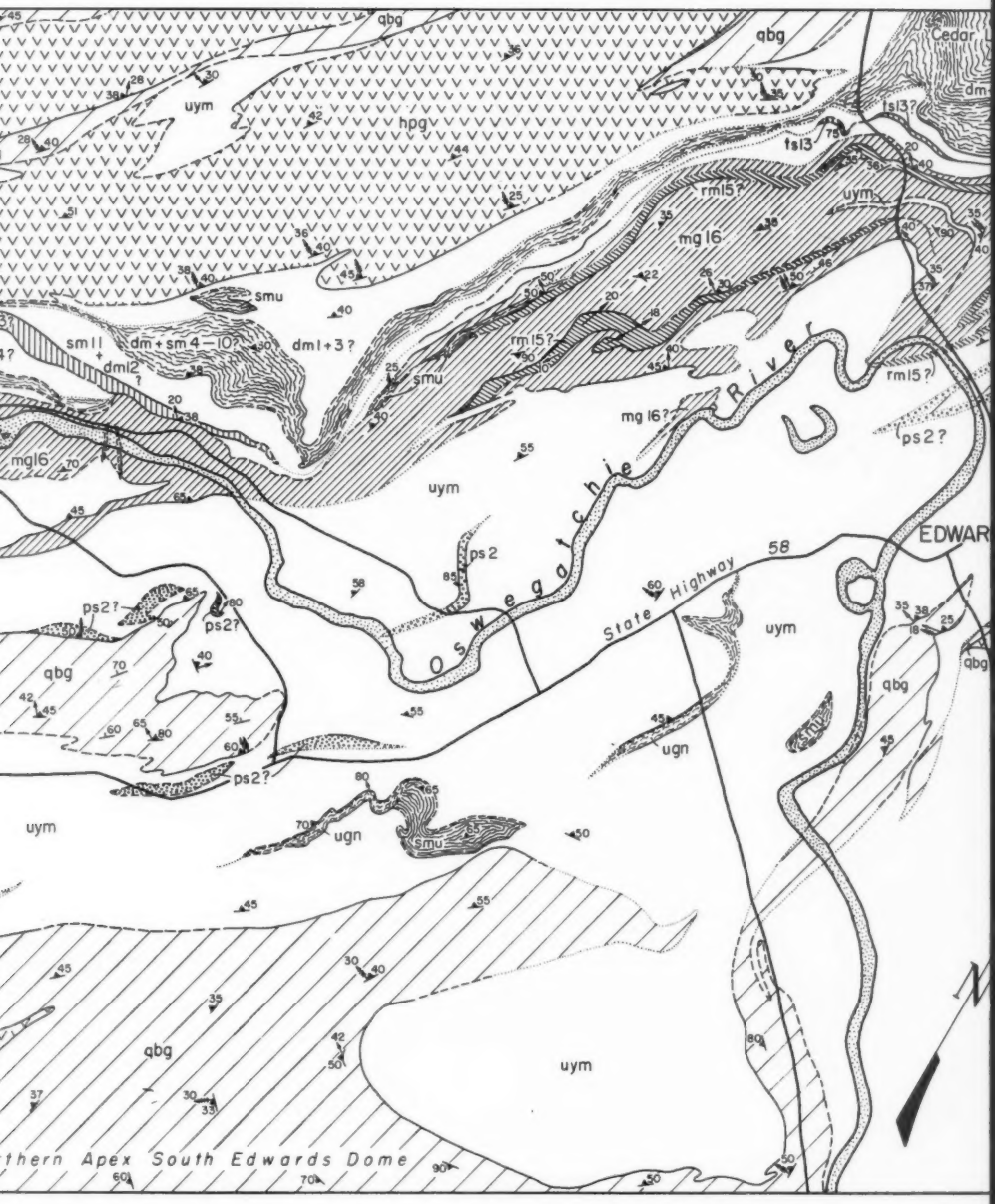
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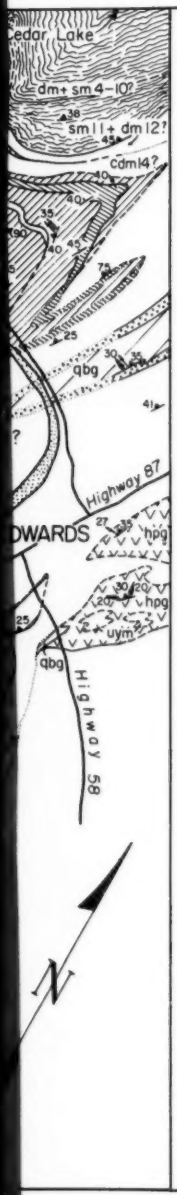

Explanation

Precambrian

Grenville Series

- uym — Marble, undifferentiated, largely dolomite, partly silicated, locally calcitic
- smu — Marble, undifferentiated, highly siliceous and silicated
- dm + sm 4-11 — ? — Dolomite and silicated dolomite units 4-11?, undifferentiated
  - sml — Dolomite interlayered with diopsidic rock
  - gml0 — Gypsiferous anhydrite and talcose marble
  - dm9 — Dolomite; slightly fetid, locally silicated
  - sm8 — Silicated dolomite; dolomite interlayered with quartz, and serpentinous diopside
  - fd7 — Fetid dolomite, graphitic
  - sm6 — Silicated dolomite; dolomite containing quartz-diopside layers
  - dm5 — Dolomite, locally diopsidic
  - sm4 — Silicated dolomite; dolomite interlayered with quartz, diopside, serpentine, talc
- dm3 — Dolomite, locally silicated
- ps2 — Pyritic schist; quartz-mica-feldspar-chlorite-graphite
- dml — Basal dolomite, locally silicated
- qbg — Quartz-biotite-oligoclase gneiss (migmatitic)

Upper Cambrian (and lower Ordovician?)

- Ep — Potsdam sandstone and siliceous breccia

Granite

- hpg — Granite; gneissic, largely equigranular, biotitic (Hermon type)
- ccg — Granite, equigranular, alaskitic (California type)

Amphibolite

- am — Amphibolite; partly granitized gabbro, partly probably volcanic and carbonate parent rocks

Paragneiss

- ugn — Paragneiss (largely fragmented median gneiss?)

Median gneiss

- mgl6 — Median gneiss; quartz-two mica-two feldspar migmatite and amphibolite

Rusty marble

- rml5 — Rusty marble; calcitic with diopside, mica, feldspars, tremolite, quartz and pyrite

Partly calcitic, partly dolomitic marble

- cdm14 — Partly calcitic, partly dolomitic marble; silicated

Tremolite-anthophyllite-serpentine-talc schist

- ts13 — Tremolite-anthophyllite-serpentine-talc schist, in part calcitic

Dolomite, slightly fetid, locally diopsidic

- dml2 — Dolomite, slightly fetid, locally diopsidic

Geologic boundaries

- Known
- Readily inferred
- Hypothetical

Discontinuous deformation, crackled, brecciated, faulted rock

Planar elements

- 36 — Strike and dip of bedding or oldest recognizable foliation in given exposure
- 28 — Strike and dip of younger divergent foliation (commonly an axial plane foliation)

Linear elements

- 25 — Plunge of crenulations and small folds
- 30 — Plunge of larger folds (amplitude > 25 feet)
- 47 — Plunge of subparallel elongate minerals or mineral aggregates

State or township hard surface road

0 1000 2000 3000

Scale in Feet

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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REVISION OF GRENVILLE STRATIGRAPHY AND STRUCTURE IN THE BALMAT-EDWARDS DISTRICT, NORTHWEST ADIRONDACKS, NEW YORK

BY JOHN S. BROWN AND A. E. J. ENGEL

ABSTRACT

Integration of much new surface and subsurface data suggests major reinterpretations of stratigraphy and structure of the Grenville series of the Precambrian in the Balmat-Edwards district, New York.

Only two major metasedimentary units appear to exist, (1) marble and (2) migmatitic paragneiss. The paragneiss seems to be about 3000 feet thick and is the oldest formation. The overlying marble may be as much as 2000 feet thick and is differentiated into 15 units. Most units are silicated dolomite; one contains anhydrite and traces of halite, another hydrogen sulfide and graphite. A potassic migmatite (injected sandy shale), about 400 feet thick, and minor marble overlie this sequence. Major variations in composition and form of metasedimentary units are common, but most variations are metamorphic in origin.

The metasedimentary sequence is complexly sheared and intricately plicated into a series of northeast-trending, gently plunging folds. These merge into and are blurred by northwest-plunging cross folds. Both types of folds range from crumples to folds with either an amplitude or a radius of curvature of a mile or more. The northeast-trending folds are accordant elements of a regional system. Cross folds are confined largely to zones on opposite sides of the Grenville Lowlands where the lowlands merge into igneous massifs. Parts of these zones are major shears, involving displacements of at least 3 miles, along which stratigraphic units are obliterated.

The two fold sets and shear zones may be ascribed to either (1) closely related stages in a gigantic, upward diapiric flow of metasediments and intrusives of the Grenville Lowlands in response to southeast-northwest crustal shortening or (2) more distinctly separated periods of deformation, in which the cross folds formed through refolding of the pre-existing structures in response to a northeastward crustal couple. The second interpretation is preferred largely because of (1) the large size of the cross folds and of the belts formed by them, (2) the common direction sense of cross folds, and (3) evidence that the axes of many cross folds intersect axes of the northeast-trending, gently plunging folds at large angles.

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Introduction

The writers have been concerned with rocks of the Precambrian Grenville series in the northwestern Adirondacks for a considerable time, Brown primarily as geologist for the St. Joseph Lead Company, which has mined zinc ore in the Balmat-Edwards area on an important scale since 1926, and Engel as geologist of the U. S. Geological Survey, interested in the talc deposits of the area as well as the regional geology. The papers on the geology of the area most pertinent to this discussion are one by Brown (1936) and two by Engel and Engel on the Grenville series (1953a; 1953b), which contain a bibliography of previous work. Since Brown's article in 1936, the St. Joseph Lead Company has done a great deal of diamond drilling and underground development that shows a much clearer picture of the stratigraphy and structure, especially near Balmat. Engel has done intensive field mapping throughout the region and has supplemented this by chemical and petrographic studies.

Following a series of field conferences in 1953, it was agreed that by pooling the information available to both authors it would be possible to make a more significant contribution to the understanding of basic stratigraphy and structural features of the Grenville series in this area than by either's single efforts.

The St. Joseph Lead Co. kindly permitted the writers to use company information on the geology of the area; the data are primarily those accumulated by John S. Brown and Norman H. Donald, Jr., who was first Brown's assistant and later his successor as geologist for the lead company in this area.

Regional Setting

The Balmat-Edwards district lies in the Grenville Lowlands of the northwest Adirondack Mountains, along and near the abrupt transition of the Lowlands into the dominantly granitic and syenitic perimeter of the Adirondack igneous massif (*see* Pl. 1 in Buddington, 1939; Fig. 1 in Engel and Engel, 1953b).

Within the Lowlands there appear to be either three or five major metasedimentary units of the Grenville Series. The alternative numbers of units recognized reflect two interpretations of structural relations. In either interpretation, these units form a crudely arcuate pattern that trends northeast, sheathing the rounded margin of the massif. Assuming as Engel did (Engel and Engel, 1953b, Figs. 1, 2, Table 1) that five units are present, the sequence from southeast to northwest (top to bottom) across the lithologic trend is as follows: (1) feldspathic gneiss; (2) marble (upper marble belt), which forms the host rock to the talc and zinc deposits in the Balmat-Edwards district; (3) quartz-biotite-oligoclase gneiss, which forms the northwestern boundary of the Balmat-Edwards district and protrudes through the marble on the southeast side of the district; (4) siliceous dolomite marble (central or Gouverneur marble belt); and (5) siliceous and gneissic marble (Black Lake metasedimentary belt). Conceivably the marble units 2, 4, and 5 are but parts of a single unit flanking the opposite sides of an obscure isoclinal fold in the quartz-biotite-oligoclase gneiss (Engel and Engel, 1953b, p. 1058).

If, however, no such obscure isocline exists, it seems probable that a major structural element in the Grenville Lowlands is a bulbous anticlinorium (Engel and Engel, 1953b, Fig. 2). The axis of this anticlinorium would neces-

sarily trend northeast and cause the observed northeast regional lithologic trend to the metasedimentary units. Consequently, this hypothesis represents the Grenville series in the northwest Adirondacks as having its lower (older) beds lying to the northwest and its upper major unit, the feldspathic granulite, adjoining the granosyenite complex (Buddington, 1948) that forms the outer part of the central Adirondack massif.

The southeast flank of the inferred anticlinorium (or the southeast flank of the possible isoclinal fold in the quartz-biotite-oligoclase gneiss) would be overturned to the southeast against the northwest (synclinal?) border area of the Adirondack igneous massif. The feldspathic gneiss, upper marble, and quartz-biotite-oligoclase gniess that form the southeastern flank of the anticlinorium, or isoclinal fold in gneiss, are overturned throughout much of their known extent. In either hypothesis, therefore, the Balmat-Edwards district lies along the southeast, overturned flank of a major anticlinorial or anticlinal structure with zinc and talc deposits largely within the upper marble belt (Engel and Engel, 1953b, Fig. 2, zone 4).

The relations of the structural features within the central part of either the anticlinorium or anticlinal structure in the gneiss to those along the southeastern margin of either structure postulated are important in any discussion of structure in the Balmat-Edwards district.

In the central part of the Grenville Lowlands, just southeast of the core of the postulated regional anticlinorium (or along and just northwest of the axis of any major isoclinal anticline in the gneiss), the axes of most mappable folds trend northeast. The opposed ends of these folds plunge either northeast or southwest at angles not exceeding 30° (Engel, 1949, Fig. 1). The visible, central segments of the fold axes are nearly horizontal. Consequently, these folds may be interpreted as typical components of the regional anticlinorial or anticlinal structure in that they are conformable in orientation with the larger structures, and presumably evolved as a product of the same regional forces that formed the larger structures. Hereafter, these northeast-trending, gently plunging folds are referred to as accordant folds.

Southeastward from this central belt of accordant folds and nearer the margin of the Adirondack igneous massif most of the visible folds are more closely folded and more complicated in form. And although entire folds rarely can be mapped or reconstructed with assurance, it is clear that accordant folds or segments of folds of any size are either uncommon or obliterated. The decipherable (remaining?) segments of fold axes diverge abruptly in the direction of plunge from the northeast or southwest regional trends into orientations north and west near or essentially accordant with the direction of northwest (overturned?) dip of the rock units (Engel, 1949, p. 769, Fig. 1). Consequently the rake of these folds is between 65° and 90°. These steeply plunging folds are referred to as cross folds, inasmuch as their northwest trends are about normal to the northeast trend of major rock units in the lowlands, and therefore across both the trend of accordant folds and of the assumed lowlands anticlinorium or major anticline. The tectonic belt characterized by the cross folds commonly is several miles or more in width, and extends along and into the massif as is shown by Buddington and Leonard (In press) and Engel (In press).

The amount of plunge of most cross folds is from 30°–80° NW. The tectonic belt thus formed both includes and coincides in dip with the northwestward-dipping contact of the lowlands and massif.

In both the central belt of accordant gently plunging folds and in the southeast belt of northwest-plunging cross folds, most lineations resulting from subparallelism of elongate minerals, aligned crinkles, and intersecting foliations are parallel to the axes of large associated folds. The principal exceptions appear in zones of marked cataclassis—mortar gneisses and mylonites. In these rocks, strong lineations parallel the inferred direction of major movement during the granulation process and are at angles of 70°–90° to most associated fold axes whether these be accordant or cross folds.

The Balmat-Edwards district lies largely

within the belt of cross folds, but its westernmost part coincides with the zone of transition between the belt of cross folds and the central belt of accordant folds. For example, most visible segments of major folds in the central, east, and northeast parts of the district are cross folds that plunge 40°–70° NW. In contrast, most obvious segments of fold axes in the extreme southwest part of the district (Balmat-Kelloggs Corners area) plunge less steeply (5°–40°) and trend in a direction either intermediate between the cross and accordant folds, or to the northeast, subparallel to the accordant folds immediately to the northwest (Pl. 1).

Notably, at least two large folds in the district, the California anticline and the South Edwards dome, seem to be of the accordant type at their southwestern ends, whereas their northeastern ends converge in direction and amount of plunge toward well-defined cross folds. Outside the district, other folds show this same hybrid form. Their axes as viewed in longitudinal section are abruptly, although asymmetrically, arched. In general, these hybrid folds lie along or near the zone of abrupt transition between the belts of accordant and cross folds.

Other than the hybrid types, most large folds in the district have features which suggest that they are refolded. The large fold around Sylvia Lake definitely is refolded, and the big fishhook-shaped fold just north of Edwards probably is refolded (Fig. 2; Pl. 2). At these and most other places in the district, the initial folds appear to have been of the accordant type, whereas the refolding process has produced typical cross folds.

Clearly the Grenville series flowed extensively during the evolution of accordant, hybrid, and cross folds. The hybrid and cross folds must have formed during or after the concluding growth stages of the accordant folds. Possibly these several fold types may be the products of one complex deformation involving a diapiric or extrusionlike mushrooming of the Grenville series. This interpretation was suggested earlier by Engel (1949, p. 782). However, the data accumulated in the last 6 years suggests that two more distinct periods of folding were involved.

This opinion stems principally from recognition of several features, especially (1) the large size of the belt characterized by cross folds; (2) the large size of the individual cross folds (as much as several miles from flank to flank and from crest to trough); (3) the common asymmetry of the cross folds; and (4) the large angles of intersection of fold axes, which suggests that many cross folds are formed by refolding of accordant folds. Seemingly, some large accordant folds were refolded almost at right angles to their initial axes.

Relations of this type would seem best explained by marked reorientation of major (regional) forces in the earth's crust; that is, two deformations. Obviously, much more data and genius are required to relate in detail the times, the orientations, and the origins of the forces involved. Whatever the ultimate conclusions, the available information requires important revisions in the interpretations of the stratigraphy and structural features in the Balmat-Edwards district.

Balmat-Edwards District

Balmat Stratigraphy

In Brown's original mapping (1936, Fig. 1) as in that of Cushing (Cushing and Newland, 1925), Buddington (1917), and Gilluly (1945), it was realized that the marble between Balmat and Edwards contained many distinctive lithologic units. These have been so disrupted by deformation and so obscured by glacial overburden that commonly only one or two units were differentiated in mapping. The most persistent, distinctive, and well-exposed unit was dubbed the median gneiss by Brown (1936, p. 238), since it appeared to be in about the middle of the marble belt and to extend for several miles southwest of Edwards toward Balmat. Its width of outcrop in the Edwards area ranges from 1000 to 1500 feet, indicating a thickness of perhaps 600 feet. Halfway between Edwards and Balmat, the median gneiss disappears under cover although it crops out to the southwest in the Balmat section considerably thinner, not more than 200–300 feet thick. In the vicinity of Sylvia Lake, Cushing and Newland (1925) also attempted a very crude subdivision into more and less siliceous marble, and Gilluly (1945) distinguished the pyritic schist unit.

During an extensive prospecting program at Balmat and around Sylvia Lake initiated in 1947, N. H. Donald, Jr. recognized in the drill cores many intersections of a peculiar marker bed or unit in the middle of the Balmat marble area, midway between the median gneiss on the south and the enclosing quartz-biotite-oligoclase gneiss to the north. This layer is soft and soluble because of high talc and gypsum content, and it does not outcrop. It was almost unfailingly identifiable, however, in drill cores. Utilizing this marker, Brown and Donald were able to decipher many complex structures within the marble and to subdivide the Grenville marble in the Balmat area into 15 well-defined units. Field conferences involving Brown, Donald, and Engel disclosed that most of these units in the Balmat area also were being mapped by Engel who had traced them northeastward through much of the district in surface exposures and in the talc mines (Engel, in manuscript). Additional data in the Hyatt and Edwards areas were obtained by Brown from subsurface exploration for zinc.

The stratigraphic sequence in the marble of the district is best known in the Sylvia Lake area where abundant surface and subsurface information has been collected (Pl. 2). This sequence is fairly typical of the marble throughout the district. The lateral variations in sedimentary units in the marble, across the district, do not appear to be great. The metamorphic overprint does vary greatly from place to place, however, and this fact makes a broad stratigraphic synthesis hypothetical at best.

If the upper marble belt (siliceous dolomite marble) and quartz-biotite-oligoclase gneiss are indeed overturned, the oldest unit in the marble within the district is that immediately adjacent to the gneiss. And, if the stratigraphic and structural features on Plate 1 are correct, the detailed stratigraphic sequence from oldest to youngest in the Sylvia Lake area, and presumably throughout the district, is as follows.

UNIT 1 (basal dolomite dm 1). This dolomite lies adjacent to the enclosing quartz-biotite-oligoclase gneiss (Engel and Engel, 1953b) and separates it from unit 2 (pyritic schist) in the Balmat area (Pls. 1, 2). The only area of good exposure of the basal dolomite in the Sylvia Lake area is west of the township road that extends north from Kellogg Corners (Pl. 1). Elsewhere the unit underlies a covered lowland between quartz-biotite-oligoclase gneiss and pyritic schist like the shallow valley occupied by Mud Pond (Pl. 2). At most places the basal dolomite seems to range from 100 to 200 feet in thickness, although it is either very thin or locally absent (disrupted?) 1000 yards southwest of Mud Pond.

Weathered exposures are light to medium gray, commonly faintly layered. Freshly broken pieces are white to buff or gray (graphitic). The basal dolomite is remarkably pure, medium- to coarse-grained in most places. However, small clots of serpentinous diopside, wisps of graphite, and disseminated grains of feldspar, phlogopite, and tremolite are included.

Examination of the 14 thin sections of the basal dolomite where the dolomite is not obviously injected or secondarily replaced indicates the mineralogical composition shown in Table 1. The tabulated modal data are of particular interest in that they fit equally well the composition of most dolomite units (units 3, 5, 9, 12) stratigraphically higher in the section. These dolomite units are distinguishable only because of their unique relations to other distinctive units of the sequence.

UNIT 2 (pyritic schist). In the Sylvia Lake area this unit outcrops on a broad arc nearly continuously from the village of Fowler west and south almost to Kellogg Corners where it pinches out, probably because of stretching during folding (Pl. 2). An average thickness of the pyritic schist in this area is about 200 feet, but it is considerably wider over most of its outcrop because of its rather gentle dip (Pl. 2).

The pyritic schist is one of the key units in the reconstruction of a stratigraphic sequence around Sylvia Lake and elsewhere in the district, for it seems to have wide distribution with a striking and presumably uniform composition and a fair tendency to outcrop. Its pyrite content and its thin soil are inhospitable to vegetation, and its rusty brown, yellow, and brownish-black outcrops are conspicuous.

Basically the unit is a fine-grained, quartz-mica-feldspar schist, slightly graphitic, chloritic, and strongly but erratically pyritic. It

has been considered and prospected superficially as a possible source of commercial pyrite (Buddington, 1917; Smyth, 1912; Prucha, 1953, p. 52–54). Oxidation of constituent pyrite to hematite also led to much prospecting of the schist and the adjacent dolomite for red hematite iron ore, but the deposits are insignificant in this area. In the vicinity of Balmat this unit is separable into subunits which in stratigraphic order from bottom to top include: (1) pyrite-chlorite-quartz-feldspar schist, much sheared; (2) a serpentinous, diopsidic limestone, in part converted into hard, black, skarnlike lenses; (3) pyritic, biotite-quartz-feldspar migmatite; and (4) pyrite-quartz-microcline granulite. Each of the lithologic types appears in irregular zonelike forms which are essentially parallel to each other and to the contacts of schist and marble.

TABLE 1.—MINERALOGICAL COMPOSITION OF THE BASAL DOLOMITE IN THE MARBLE OF THE BALMAT-EDWARDS AREA*
In volume per cent

Mineral†	Sections in which mineral is present	Volume per cent		
		High	Low	Mean
Dolomite	14	99.8	93	97.4
Calcite	....	..	...	...
Diopside	4	1.5	0.03	0.6
Tremolite	2	2.1	0.8	1.4
Serpentine and talc	10	4.5	0.03	0.84
Plagioclase	5	2.0	0.3	1.0
Potash feldspar	3	3.0	0.2	1.2
Quartz	4	2.0	0.3	1.1
Phlogopite	3	1.0	0.04	0.4

*As indicated by examination of 14 thin sections.

†Also occasional grains (<0.5) of magnetite, sphene, graphite, iron oxide, sericite.

The highly pyritic, chloritic parts of the pyritic schist commonly show a subconchoidal to blocky fracture and a crude fissility that diverges both from bedding and from the axial planes of more obvious folds. Accurate modal counts are almost impossible for the specimens tend to be fine-grained and in part cataclastic. Principal mineral constituents are chlorite, serpentine, sericite, sillimanite, quartz, feldspar, pyrite, and iron oxides.

The limestone subunit tends to be medium- to coarse-grained (0.5–10 mm) and tough to break. It is absent locally, possibly owing to deformation. Northeast of Mud Pond almost 2400 feet, it is as much as 25 feet thick. The areas of skarnlike rock within it contain garnet, magnetite, grunerite, cummingtonite, phlogopite, and diopside.

The migmatitic subunit differs from the stratigraphically overlying granulite subunit in containing appreciable plagioclase and in being more coarsely and distinctly injected *lit-par-lit* by granitic and pegmatitic lenses. Nine thin sections of the least injected migmatite show the following range in mineral composition: quartz 25 to 51, average 41; potash feldspar 12 to 29, average 17; plagioclase 2 to 12, average 5; muscovite-sericite 3 to 10, average 5.

Twelve thin sections of the granulite show the following range and average mineral composition in volume per cent: quartz 28 to 40, average 36; potash feldspar (almost wholly microcline) 30 to 52, average 41 per cent; pyrite 3 to 15, average 7; and muscovite-sericite 2 to 27, average 13; biotite 1 to 4, average 2.

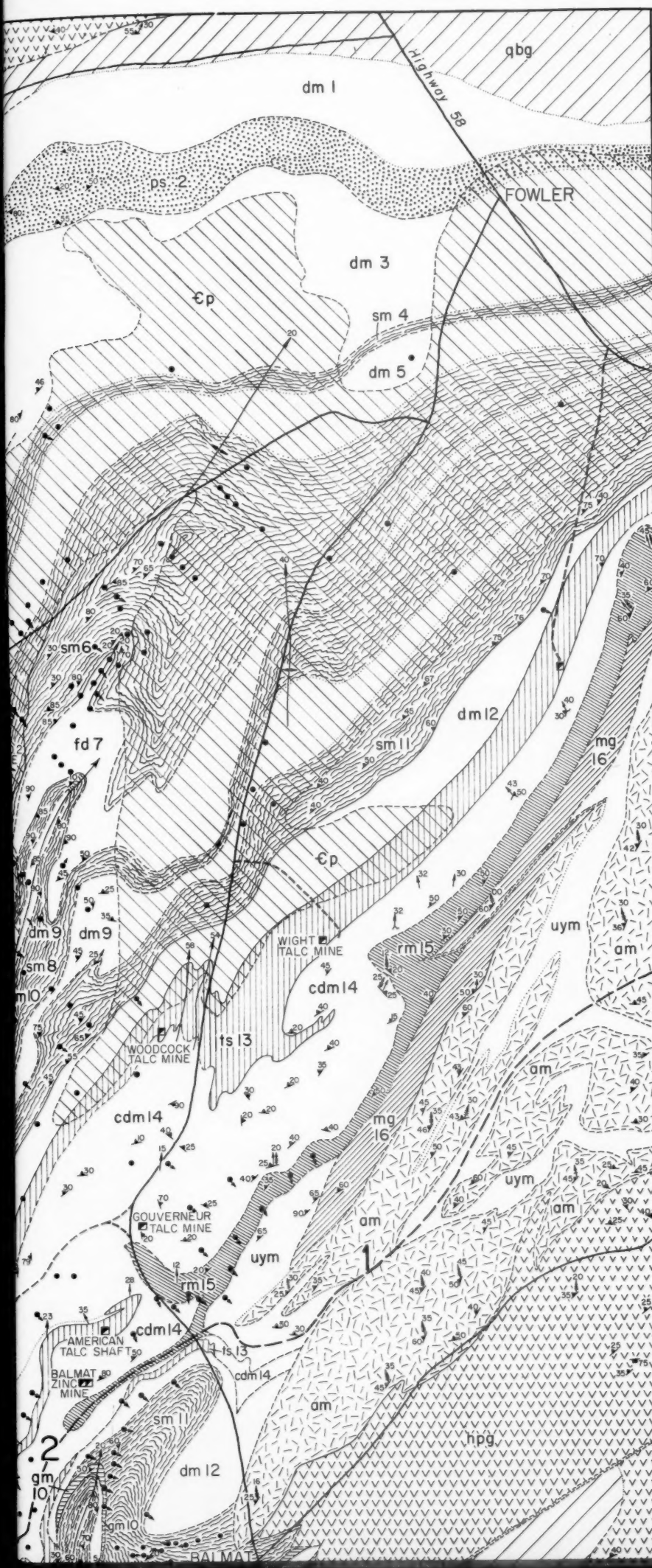
Both migmatite and granulite subunits contain accessory apatite, chlorite, calcite, garnet, sillimanite, and zircon.

In places the sillimanite (largely replaced by quartz and sericite) appears as disseminated needles. More often, however, it is concentrated in siliceous, sericitic augen and scale-shaped clusters. These clusters commonly show both a planar and linear parallelism. The lineation is accordant with the axes of the folds in the pyritic schist, but the planar surfaces defined by the augen and scales commonly diverge slightly from the older dominant lithologic layering to define a definite although not too obvious second foliation, whose intersection with the more contrasting rock layers is parallel to axes of folding in the schist.

UNIT 3. This unit (Pl. 1, dm 3) is a medium-crystalline to coarsely crystalline dolomite commonly 150 to 250 feet thick. It is similar in physical and chemical features to the basal dolomite described as unit 1, and these two dolomites are distinguishable only where they are separated by pyritic schist. Northeast of Fowler and southwest of Sylvia Lake where the pyritic schist feathers out, these dolomite

qbg
hpg
qbg
hpg
qbg
qm
€p
dm 1
ps:2
sm 4
Mud
Pond
dm 3
qbg
sm 4
dm 5
sm 4
€p
sm
sm 4
dm 5
€p
dm 1
gm 10
S y l v i a
qbg
sm 4
dm 3
dm 5
L a k
sm 8
dm 9
4

Precambrian
Grenville series
Highway 58
FOWLER
qbg
dm 1
ps 2
dm 3
€p
sm 4
dm 5
sm 6
fd 7
BALMAT NO 2 ZINC MINE
dm 9
sm 8
gm 10
sm 11
dm 12
mg 16
rm 15
uym
am
cdm 14
ts 13
WIGHT TALC MINE
WOODCOCK TALC MINE
GOUVERNEUR TALC MINE
AMERICAN TALC SHAFT
BALMAT ZINC MINE
hpg
BALMAT CORNERS
1
2
3


qbg
dm 1
Highway 58
ps. 2
FOWLER
dm 3
€p
sm 4
dm 5
sm6
fd 7
dm 12
sm11
mg 16
€p
dm 9
dm 9
sm8
rm10
WIGHT TALC MINE
rm15
uym
am
cdm14
WOODCOCK TALC MINE
ts 13
am
cdm14
mg 16
GOUVERNEUR TALC MINE
uym
am
uym
rm15
cdm14
AMERICAN TALC SHAFT
ts 13
BALMAT ZINC MINE
cdm14
am
sm 11
hpg
gm 10
dm 12
gm10
BALMAT

Explanation

- Cp — Upper Cambrian (and lower Ordovician?) Potsdam sandstone and siliceous breccia
- hpg — Granite; gneissic, largely equigranular, biotitic (Hermon type)
- am — Amphibolite; partly granitized gabbro, partly probably volcanic and carbonate parent rocks
- uym — Marble, undifferentiated, largely dolomite, partly silicated locally calcitic

Precambrian — Grenville series

- mg 16 — Median gneiss; quartz-two mica-two feldspar migmatite and amphibolite
- rm 15 — Rusty marble; calcitic with diopside, mica, feldspars, tremolite, quartz and pyrite
- cdm 14 — Partly calcitic, partly dolomitic marble; silicated
- ts 13 — Tremolite-anthophyllite-serpentine-talc schist, in part calcitic
- dm 12 — Dolomite, slightly fetid, locally diopsidic
- sm 11 — Dolomite interlayered with diopsidic rock
- gm 10 — Gypsiferous anhydrite and talcose marble
- dm 9 — Dolomite; slightly fetid locally silicated
- sm 8 — Silicated dolomite; dolomite interlayered with quartz, and serpentinous diopside
- fd 7 — Fetid dolomite, graphitic
- sm 6 — Silicated dolomite; dolomite containing quartz-diopside layers
- dm 5 — Dolomite; locally diopsidic
- sm 4 — Silicated dolomite; dolomite interlayered with quartz, diopside, serpentine, talc
- dm 3 — Dolomite, locally silicated
- ps 2 — Pyritic schist; quartz-mica-feldspar-chlorite-graphite
- dm 1 — Basal dolomite, locally silicated
- qbg — Quartz-biotite-oligoclase gneiss (migmatitic)

Geologic boundaries
- Known
- Readily inferred
- Hypothetical

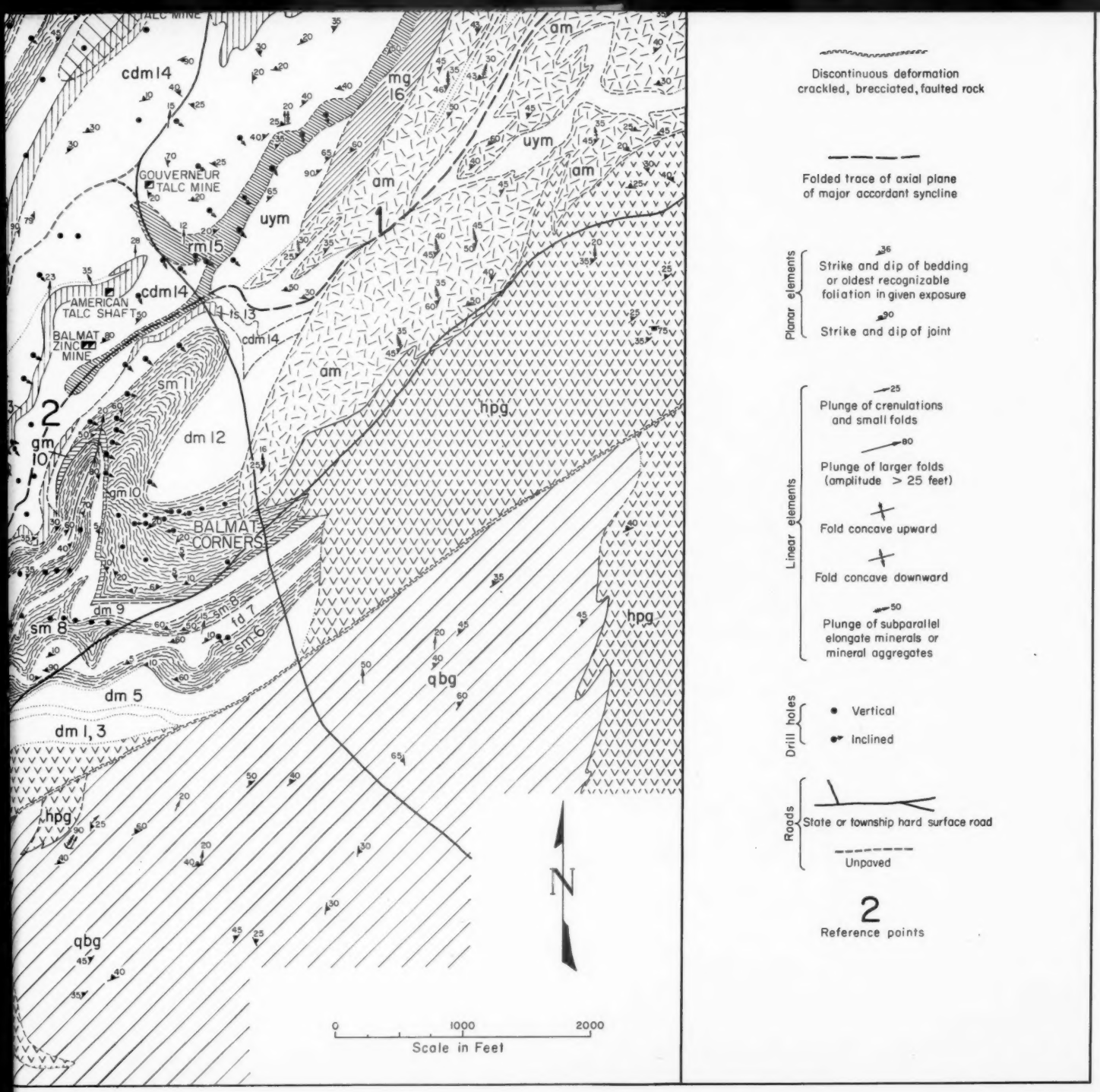
Discontinuous deformation
crackled, brecciated, faulted rock

Folded trace of axial plane of major accordant syncline

Planar elements
- 36 — Strike and dip of bedding or oldest recognizable foliation in given exposure
- 90 — Strike and dip of joint

elements
- 25 — Plunge of crenulations and small folds
- 80 — Plunge of larger folds (amplitude > 25 feet)
- Fold concave upward

GEOLOGIC MAP OF THE BALMAT AREA



THE BALMAT AREA

units (Pl. 1, units 1, 3) are mapped as one basal dolomite zone. Good exposures of the unit 3 occur almost continuously along the concave (eastern) side of the arc described by the pyritic schist from a point about 900 feet north of Kellogg Corners northeast to a point half a mile west of Fowler. Northeast of Fowler for about 1½ miles the pyritic schist unit is exposed in only one small outcrop. Possibly it is disrupted through much of the area, and dolomite units 1 and 3 are merged into one dolomite unit.

UNIT 4. Unit 4 is a silicated dolomite (Pl. 1, sm 4) commonly 200–300 feet thick. It is characterized by alternating layers and lenses of dolomite and serpentinous and talcose diopside rock. Most of the diopsidic layers are one to several inches thick and variously contorted and disrupted into knots and lenticles (Pl. 3). Commonly some quartz appears as a core to the diopsidic rock. The serpentine and talc occur as replacements of the diopside. The dolomite layers are several inches to several feet thick. At the base of the unit, a dolomite subunit 60 to 100 feet thick separates the main part of the unit from a subunit of knotty diopside-quartz lenses totaling 15 to 25 feet in thickness (Pl. 4, fig. 1). This basal subunit is mappable throughout the area west and northwest of Sylvia Lake and is shown on Plate 2.

In weathered outcrops the diopsidic lenses and layers are buff or light gray and are etched out in relief above the interlayered and enveloping dolomite (Pl. 3, fig. 2). On fresh surfaces the dolomite is white, the diopside, cream-colored. Much of the talcose alteration of the diopside is silvery gray to almost black. The serpentine may be buff or various shades of green.

The proportion of dolomite to silicate lenses and layers varies along and across the strike, but in general this unit contains roughly 60 per cent dolomite and 40 per cent silicates. The relations of the silicates to dolomite indicate that the diopside formed as a reaction between pre-existing quartz and dolomite layers. Except locally, the reaction was incomplete, hence the residual quartz core in most silicate layers. The enveloping diopside sheath ranges greatly in thickness from one-eighth inch to a few inches where the reaction involved most or all of the quartz. The serpentine and talc are retrograde alterations of the diopside, which locally obliterate much of the diopside. Where serpentine or talc are major constituents some calcite appears in the assemblage (Engel, in manuscript). Both dolomite and the local areas of calcite are medium- to coarse-grained (1–10 mm). Most quartz and diopside grains range from 0.5 to 5 mm in diameter, whereas the talc and serpentine commonly are microcrystalline. Most dolomite layers contain traces of feldspar (plagioclase and potash), phlogopite, pyrite, graphite, and iron oxides.

UNIT 5. A medium-crystalline to coarsely crystalline dolomite commonly 100 to 175 feet thick comprises unit 5. Weathered exposures are gray, but fresh surfaces are white to cream. This dolomite, like units 1 and 3, contains rare, scattered clots of serpentinous and talcose diopside, quartz, and traces of phlogopite, graphite, feldspars, pyrite, and iron oxides.

The best exposures of this dolomite unit in the Balmat area are north and west of Sylvia Lake and northeast of Kellogg Corners (Pls. 2; 4, fig. 1). Where unit 5 occurs southeast and northeast of Sylvia Lake (Pls. 1, 2) one or both of the enclosing silicated units 4 and 6 are sufficiently thinned, contorted, or disrupted and so poorly exposed that the dolomite units 3 and 5 are easily confused. In these areas the forms and interrelations of units 3, 4, 5, and 6 were determined first from subsurface data and subsequently sought out in the scanty surface exposures.

UNIT 6. Unit 6 consists of a siliceous and silicated dolomite zone with interlayers of dolomite and somewhat talcose and serpentinous quartz-diopside rock. This unit is broadly like unit 4. Unit 6 is the host to the zinc ore in the Balmat No. 2 mine north of Sylvia Lake and hence has been thoroughly explored there. Several subdivisions, which have been made in the mine, can also be followed in the surface exposures around Sylvia Lake. These subdivisions are, from base to top:

6A, dominantly diopsidic quartzite ranging from 50 to 200 feet in thickness. This subunit includes both thick and very thin layers; less than a third of them are carbonate. The proportion of quartz to diopside in the silicate layers ranges appreciably from about 10:1 to 1:3. As the per cent diopside increases the amount of interlayered carbonate decreases.

6B, silicated dolomite in which the dolomite predominates over quartz-diopside lenses and layers by some 4:1. Thickness is 25–150 feet. Diopside predominates over quartz in most of the silicate masses, and frequently exceeds quartz by 6 to 8:1. The silicate layers and lenses are much broken and dispersed but seem to represent beds as much as 6 inches thick as well as some nodular silica.

6C, Massive, blocky quartz-diopside layers as much as 3 or 4 feet thick with 15 or 20 per cent thin dolomite interlayers. Quartz commonly predominates over diopside. Six C commonly is about 75 to 250 feet thick.

In addition to these subunits there are several narrow (an inch to a foot) talcose layers, which follow bedding, are fairly continuous in the No. 2 mine, and constitute at least local stratigraphic markers.

All the thicker silicate layers are bent, broken, and tectonically dispersed in the dolomite, which obviously was extremely mobile during metamorphism. Serpentinous and talcose alteration is common, especially in diopside, but it also appears in quartz and dolomite.

Tremolite forms small, local nests, lenses, and scattered layers. It seems to have formed both as the initial product of reaction between pre-existing quartz and dolomite and as a replacement of diopside. Diopside and tremolite, however, do not appear intimately intergrown either in this or in other parts of the marble. Scattered tiny nests of potash and plagioclase feldspar occur in both silicate and dolomite layers. Other accessory minerals include pyrite, graphite, and phlogopite.

The best surface exposures of unit 6 are in the vicinity of the No. 2 mine, and thence westward along the north side of Sylvia Lake (Pl. 2). There also are several excellent exposures of this unit west of Sylvia Lake and southwest of Balmat corners.

UNIT 7. This unit is a fetid dolomite usually 75 to 150 feet thick. The dolomite "stinkstone" commonly is a bit darker gray on weathered and fresh surfaces than the other dolomite units and emits a marked odor of H_2S when crushed. The odor is most detectable in the fresh subsurface exposures, especially exposures of the darker layers. The gray is produced by finely dispersed graphite. It is essentially identical to the dolomite units 1, 3, and 5, but because of its odor and color which are confined almost wholly to this dolomite, it is one of the best marker units in the entire sequence.

Surface exposures of the fetid dolomite occur at the northeast end (outlet) of Sylvia Lake, in the vicinity of the Balmat No. 2 mine and along the southwest side of Sylvia Lake (Pl. 2).

UNIT 8. Unit 8 is a silicated dolomite composed of alternating layers of dolomite and quartz-diopside rock. Individual layers may be very irregular in form, but most are several inches thick. Lithologically this unit is much like parts of unit 4. Similar types of serpentinous and talcose alteration of diopside appear in both units, and the relation and origins of these minerals are the same in the two units.

In the Balmat area, unit 8 is commonly, although sparsely, mineralized with sphalerite and pyrite. There are excellent surface expo-

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PLATE 3.—STRATIGRAPHIC AND STRUCTURAL FEATURES OF THE MARBLE IN THE BALMAT-EDWARD DISTRICT

FIGURE 1.—CONTACT OF NARROW SILICATED SUBZONE THAT FORMS THE BASE OF UNIT 4 WITH THE DOLOMITE OF UNIT 3

Units are overturned. This exposure is west of Sylvia Lake. Zones strike north and dip about 20°W. Lenses and nodules that define the basal part of unit 4 are diopsidic quartzite (initially chertlike?) rudely aligned in the dolomite.

FIGURE 2.—CONTORTED DIOPSIDIC QUARTZITE LAYERS (BEDS)

Weathered out in relief above the dolomite matrix in unit 4 northeast of Kellogg Corners. Camera was pointed north, and the photo is of a nearly vertical cliff. Folds plunge gently north. Note the short, overturned or vertical east flanks of the "anticlinal" drags and their longer, nearly horizontal west flanks. This asymmetric form is characteristic of most "refolds" throughout the Sylvia Lake area and throughout the District.

FIGURE 1

FIGURE 2

STRATIGRAPHIC AND STRUCTURAL FEATURES OF THE MARBLE IN THE BALMAT-EDWARDS DISTRICT

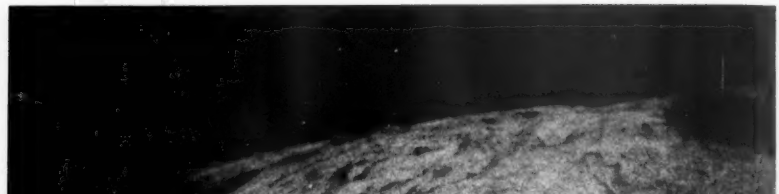

FIGURE 1

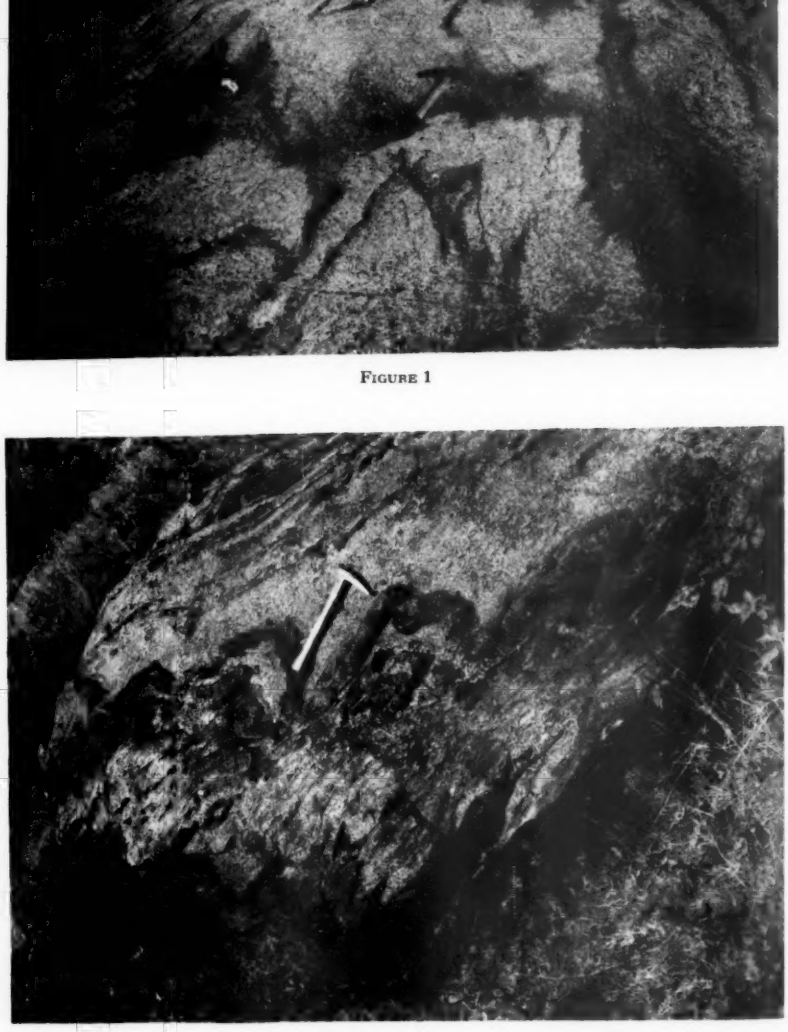

FIGURE 2

FOLDING IN THE GRENVILLE SERIES OF THE BALMAT-EDWARDS DISTRICT

sures of unit 8 along the southwest side of Sylvia Lake and at its northeast outlet.

UNIT 9. This is a dolomite, lithologically like units 1, 3, and 5, but with a few more silicate clots. It is slightly fetid at many places. The thickness of unit 9 rarely exceeds 125 feet and commonly ranges from 25 to 100 feet. The tiny rock island near the northeast shore of Sylvia Lake is formed by this unit. Other excellent exposures of unit 9 occur along the southwest shore of Sylvia Lake.

UNIT 10. In drill cores unit 10 is very distinctive and persistent and is therefore a highly useful stratigraphic unit. The unit ranges widely and abruptly in thickness from a few feet to 50 or locally 200 feet. Three subunits can be distinguished, although two of them are much more discontinuous than the third. The most persistent subunit may be as much as 30 feet in thickness; it consists of green diopsidic marble. Much of the diopside is altered to serpentine and talc, although a lot of diopside remains as embayed and sieved grains. Five to 20 per cent carbonate, largely calcite, is disseminated through the silicates.

A discontinuous schistose marble subunit composed largely of calcite, tremolite, phlogopite, and talc lies (stratigraphically) just below the diopside subunit. Most occurrences of this subunit are streaked cherry red from finely disseminated hematite. The less hematitic parts are gray. The hematite represents an oxidation product of pyrite. Seemingly this schistose subunit was permeated readily by oxidizing ground waters to depths in excess of 1000 feet, as indicated by the distribution of the hematite.

A third subunit composed of anhydrite and gypsiferous schist is closely associated with the two subunits described above. The anhydrite appears as scattered relics in the schist, and probably all the gypsum is a supergene alteration of anhydrite. The relations of the gypsum- and anhydrite-bearing subunit to the associated units strongly suggest a sedimentary origin for the calcium sulfate. In its present form however, the gypsum- and anhydrite-bearing subunit thins and thickens abruptly along the strike, and veinlets of gypsum ramify brecciated segments of the associated subunits. These relations are consistent with the interpretation that during metamorphism the subunit was composed of anhydrite that flowed extensively as a very mobile solid. As might be expected the maximum thickening of the gypsiferous schist is in the apex area of the Sylvia Lake fold beneath Sylvia Lake. There gypsum and many embayed relics of anhydrite are mixed with marble from enclosing units and squeezed into a gigantic pod some 200 or more feet thick. Undoubtedly the rapid solution and removal of surficial parts of this pod have served as the major factor in the evolution of the Sylvia Lake basin, which at places ranges from 100 to 150 feet in depth.

The soft, soluble nature of the gypsum prevents this subunit from appearing as surface outcrops, except imperfectly at one point on the northeast shore of Sylvia Lake about 500 feet south of the outlet of the Lake opposite the small islet.

UNIT 11. This is another silicated unit, averaging roughly half silicates (mostly diopside) in calcite or layers that alternate with dolomite. The more uniform layers range from 1 to 6 inches in thickness. The unit is locally as much as 100 feet thick. Most diopsidic layers are broken, contorted, and partly altered to talc and serpentine.

PLATE 4.—FOLDING IN THE GRENVILLE SERIES OF THE BALMAT-EDWARDS DISTRICT

FIGURE 1.—FLOWAGE FOLDS IN UNIT 5 NORTHWEST OF SYLVIA LAKE

Essentially pure dolomite in which the darker bands represent slightly graphitic types upon which lichen grows most abundantly.

FIGURE 2.—FOLDED CONTACT OF RUSTY MARBLE (UNIT 15) AND MEDIAN GNEISS (LOWER HALF OF PHOTO)

On the northwest flank of the Edwards fishhook fold. Beds are overturned and dip moderately north. Visible drag folds plunge about 42° NW. concordantly with the axis of the parent fishhook fold. The asymmetry of the drags accurately indicates that the apex of the parent cross fold lies to upper right of this exposure.

Unit 11 is best exposed east of Sylvia Lake, north of the Balmat zinc mine, in a series of small northeast-striking ridges (Pl. 2).

UNIT 12. This unit is a medium-crystalline to coarsely crystalline dolomite with scattered layers and clots of quartz and diopside, in part altered to serpentine and talc. This slightly silicated dolomite commonly is 200–300 feet thick. Excellent surface exposures appear just northwest of the collars of the Wight and Woodcock talc mines and along the east shore of Sylvia Lake (Pl. 2). Unit 12 is stratigraphically below the talc unit, but, because the section is mostly overturned, it is called the "hanging-wall dolomite" in the talc mines where the dolomite is extensively cut by drifts and drill cores. Locally, as in the vicinity of the Wight talc mine, and rarely in the Balmat zinc mine, it is partly replaced by diopside, sphalerite, pyrite, and galena. East of the south end of Sylvia Lake, unit 12 has been deformed into a coarse flow breccia composed of large dolomite blocks in seams of calcite and brown talc.

TABLE 2.—MINERALOGICAL COMPOSITION OF THE TALC UNIT AND COMPONENT LAYERS NEAR BALMAT

In volume per cent

	1	2	3	4
Tremolite	38	47.6	84.8	4.6
Anthophyllite	7	38.4	4.5	..
Serpentine	12	4.1	4.2	11.7
Talc	24	5.4	3.2	3.8
Quartz	3.6	3.5	2.3	3.1
Calcite	14.4	3.0	0.2	71.4
Dolomite	tr	tr	..	1.7
Fe and Mn oxides, mica, pyrite, gypsum, diopside	0.5	tr	0.8	3.7

1. Average composition of the talc unit on the fifth level of the Woodcock talc mine

2. Layer of commercial talc at the south east side (stratigraphic top ?) of the talc unit, Woodcock mine

3. Average composition of the talc unit, Balmat zinc mine

4. Silicated calcitic marble separating basal and median talc layers in the talc unit, Woodcock mine

UNIT 13. This talc unit is much complicated and locally disrupted by profound flowage of the marble in the core of the Sylvia Lake fold. Surface exposures of the talc unit are limited to the vicinities of the Woodcock and Wight mine shafts, and to several areas north and west of the Balmat zinc mine shaft. The reconstruction of the form of the talc unit southeast of Sylvia Lake as shown in Plates 1 and 2 is based largely upon the extensive subsurface data obtained in conjunction with the exploration for and mining of talc and zinc in this area.

The least contorted segments of the talc unit in the Woodcock and Wight mines are about 260 feet thick. Between these mines the talc unit is thickened to more than 400 feet in a large and bizarre fold (Pl. 2). In the Balmat zinc mine the talc unit appears to be mashed together in a tight, elongate isocline, and only locally exceeds 100 feet in thickness.

The talc unit is as complex in composition as in form. However, numerous large lenses and layers in it consist of tremolite variously altered to anthophyllite, serpentine, and talc. At any given site these minerals have formed in the order named—with overlap—largely as replacements of a pre-existing siliceous dolomite unit. The stratigraphic control of the talc appears to be remarkably rigorous, considering the inferred mobility of the marble at the time of replacement. In the vicinity of the Woodcock and Wight mines (Pl. 2), the talc unit is readily differentiated into three beds of tremolitic talc and several thinner beds interlayered with silicated, calcitic marble. At the Balmat zinc mine where the unit is thinned and complexly folded, most of it is highly tremolitic. Commonly the talc unit is distinctly layered to schistose. Most component minerals are in grains visible to the unaided eye, and tremolite in blades as long as half an inch is plentiful.

An average mineralogical composition of the talc belt in the vicinity of several mines in the Balmat area is given in Table 2, together with the composition of two contrasting subunits.

UNIT 14. Unit 14 is a quartzose calcitic marble commonly 200–350 feet thick. The carbonate in unit 14 is calcite through most of the Balmat area and northeast as far as Talcville. Commonly this unit is from 50 to 80 per cent calcite with uniformly and thinly layered quartz and diopside layers. These are much disrupted except locally. The close association of

siliceous calcitic marble with the thicker parts of talc belts and the occurrence of dolomite in unit 14 in areas such as that northeast of Talcville where talc is thinned or absent is believed to reflect important metamorphic changes in these units. The most important of these is that magnesia seems to have been extracted from unit 14 and fixed in the talc.

The exposures of the siliceous calcite marble south of the Wight and Arnold talc mines show variations in lithology typical of the calcitic phase. In this segment of unit 14, calcite constitutes about 60 per cent by volume of the rock, quartz 20 per cent, diposide 10 per cent, with feldspar 2 per cent and tremolite 2 per cent. Accessories include phlogopite, pyrite, and graphite. Thickness of the unit is approximately 125 feet.

As the unit is traced in either direction, most of the quartz-diopside layers (relict beds) appear as broken and complexly dispersed fragments in a calcite marble matrix (Pl. 3). In the area 2000–3000 feet north-northwest of Balmat, the calcitic marble is complexly interfolded with associated units 12, 13, and 15.

UNIT 15. This unit is a complexly silicated marble, locally pegmatitic. In most occurrences north of Balmat, the rusty marble is 100–150 feet thick. There, as at most exposures of this unit, the rock weathers to a rusty brown, friable marble. The rusty appearance is due to the oxidation and hydration of included pyrite. Component layers include highly diopsidic, feldspathic, tremolitic, and calcitic types. All are pyritic, and most contain phlogopite and quartz.

The mineral composition of four specimens of rusty marble in the Balmat area is indicated in Table 3, together with a mean of 22 specimens taken from exposures of what is inferred to be rusty marble in other parts of the district. No other unit of this general type is known in the marble.

East of the Balmat zinc mine and the Balmat road at the southwestern termination of the median gneiss, a predominantly calcitic marble occurs as a lens between the rusty marble and the median gneiss (unit 16). This marble may be a part of unit 14 and perhaps others intruded into it during the evolution of the complex folds in this area. It may, however, be a squeezed and thickened residue of a thin marble unit originally separating the rusty marble from the median gneiss. On Plates 1 and 2 this marble lens is included in the undifferentiated marble (Uym).

TABLE 3.—MINERALOGICAL COMPOSITION OF UNIT 15 (RUSTY MARBLE)

Mineral	No. of sections in which mineral is present	Balmat Area			District average*
		High	Low	Mean	22 specimens
Calcite	4	52	7	32	40.2
Diopside	3	74	0	29.1	17.9
Tremolite	3	29	0	12	8.1
Quartz	4	5	2	3.2	7.4
K-feldspar	4	20	4	10.7	19.0
Plagioclase	3	9	..	3.7	3.1
Scapolite	....	..	..	..	1.3
Phlogopite	2	23	..	7	2.0
Sphene	3	1	..	0.5	0.3
Tourmaline	1	0.1	..	0.1	0.2
Zircon	1	0.1	..	0.1	0.1
Pyrite	4	3	0.3	1.6	1.0
Apatite	2	0.2	..	0.1	0.1

*Mean composition of 22 specimens collected at exposures of this unit between Balmat and Edwards

UNIT 16. The median gneiss is a distinctly layered migmatitic rock, rich in potash feldspar, quartz, and micas. Immediately north of Balmat Corners the gneiss is about 100 feet thick. It thickens to the northeast, however, and as is noted in a succeeding page, the much thicker parts of the median gneiss in the northeast half of the district may result from duplication.

Weathered exposures of gneiss include pink buff to brown, and gray types. In general the pink exposures are composed of sugary-textured equigranular, quartz-microcline gneiss (granulite). The intermediate and darker parts of the gneiss consist predominantly of two types, a biotitic and an amphibolitic type. These several rock types commonly are interlayered, and on weathered surfaces the layers appear as alternating ribs and troughs, each several inches apart.

Some typical modal analyses of thin sections of several lithologic types are given in Table 4. No systematic distribution of these types is

apparent, except near the margins of the unit. There quartz-microcline gneiss predominates.

Sylvia Lake-Cedar Lake Stratigraphy

Most of the stratigraphic units described above can be traced around and beneath Sylvia Lake in a large complex fold (*see* Pls. 1, 2). If followed counterclockwise into the area south of Sylvia Lake and around Balmat Corners, the section becomes highly contorted, blurred, and ultimately obliterated by intrusions of granite and gabbro, and by related metamorphic features. Presumably, however, the same stratigraphic units, in part probably transitional into different compositional types, exist in the marble which curls southwestward around the California anticline and which also appears in the vicinity of Fullerville (Fig. 1; and Pl. 1). No definite detailed correlations have been made, however, in these areas of complex geology and poor exposures.

TABLE 4.—MINERALOGICAL COMPOSITION OF TYPES OF MEDIAN GNEISS
In volume per cent

Mineral	Biotitic facies*	Amphibolite facies†	Granulite facies**
Quartz	22	18	52
Microcline	40	23	38
Plagioclase	15	20	5
Biotite	19	12	1
Hornblende	R	19	....
Pyrite	R	R	R
Apatite	R	ca .5	R
Tourmaline	R	R	....
Zircon	R	R	R
Scapolite	1††	R	....
Calcite	....	1	....
Zoisite	R	....	R
Diopside	....	6††	....
Muscovite	3	1	2
Sphene	ca 0.3	ca 0.7	R

* Average of 12 sections
† Average of 5 sections
** Average of 13 sections
†† Average of 2 sections
R = rare

If the Sylvia Lake sequence is traced clockwise northeast of the lake, certain of the stratigraphic units seem to persist through Fowler to Hyatt and probably throughout the northwest side of the district to Cedar Lake and Edwards (Pl. 1).

Demonstration of the continuity of the marble throughout this area is a fundamental prerequisite to any structural synthesis in the district. The problem of stratigraphic correlation in the marble from Sylvia Lake to Cedar Lake and Edwards is complicated by many factors. For example, around Sylvia Lake the contact of the basal marble member (unit 1, basal dolomite) with stratigraphically lower quartz-biotite-oligoclase gneiss is an excellent structural and stratigraphic datum. But northeastward in the Hyatt-Talcville area (Pl. 1), this contact and most of the upper gneiss and lower marble are obliterated by granite. Moreover, just northwest of Talcville limited exposures of gneiss and marble suggest either an interfingering of the two, or a complexly infolded syncline in the gneiss (Pl. 5). The synclinal concept is favored for reasons advanced in a succeeding discussion of structural features of the district. Within the marble itself the presence of the granite is but one of many complications. Units not obliterated by granite are poorly exposed and either so disrupted or blurred by the metamorphic overprint (Engel, 1948) that serious uncertainty in correlations is introduced. Consequently the distribution of units shown on Plate 1 involves considerable inference and may not represent the exact patterns of sedimentary units.

One of the most obvious features of the stratigraphic units is their attenuation in what is inferred to be the flank area connecting the Sylvia Lake and Cedar Lake folds (Pls. 1, 2), that is between Fowler and a point just southwest of Cedar Lake which lies just north of the northeast corner of Plate 1. The abrupt narrowing of the marble belt as it is traced from the area north of Sylvia Lake toward Fowler seems the result of several factors. This area between the lake and Fowler coincides with the transition from the bulged and thickened apical area of the Sylvia Lake fold to an attenuated flank area to the northeast. The area also coincides with a change in dip of the units from the gently plunging apical area to the steeply dipping flank. Hence the changes in width of outcrop are even more exaggerated than changes in thickness of the units.

The occurrence of the large refractory node of gabbro-amphibolite southeast of Fowler almost surely played an important role in the attenuation of the marble at this point, causing it to be deformed between the amphibolite on the southeast and gneiss to the northwest. Consequently, the abrupt and major decrease both in thickness of marble and in the number of readily mappable units as bedding is traced northeast toward Fowler appears to be due in large part to deformation rather than to abrupt sedimentary lensing out of the units. This conclusion seems supported by the fact that a fair analogue of the Sylvia Lake sequence reappears again to the northeast, especially where the marble has converged and thickened in the apical area of the Edwards fold.

Northeast of the Fowler area, at least as far as the Hyatt mine, the basal dolomite and the dolomite overlying the pyritic schist remain mappable units (Pl. 1), although in several places the pyritic schist is absent (pulled apart?) east of Fowler and southwest of Hyatt. Above these dolomites, all the units from 4 to 10 are lumped as a single silicated marble unit. Better exposures would permit a more complete differentiation of the section, for some differentiation is possible in the area of the Hyatt zinc mine. There the lateral extensions of the following units noted around Sylvia Lake are clearly distinguishable: units 1, 2, 3, 6, 7, 12, 13, 14, and 15. In addition, units 4, 5, 8, 9, and 11 may exist in highly attenuated or complicated form.

Beyond Hyatt to the northeast, however, certain changes in the inferred sedimentary composition of marble units must be assumed. But the abundant granite and pegmatite present in the stratigraphically lower half of the section prevents any detailed analysis of such changes in units older than the talc belts. Pyritic schist is not present at and around Cedar Lake. However, pyritic schist is at the appropriate (?) horizon in the syncline in marble northeast of Cedar Lake (Pl. 5 , loc. 3). Tentatively this metasediment is correlated with the pyritic schist of the Balmat section.

In the stratigraphically higher parts of the marble northeast of Talcville unit 14, stratigraphically above the talc and below the rusty marble, changes abruptly from a siliceous calcitic marble to a less siliceous dolomite. In this same area the talc unit (unit 13) is poorly developed and in places absent from the section.

The talc unit is present in the marble northwest of the Edwards zinc mine at approximately the right stratigraphic interval, although it is impossible to prove that this is the same unit as talc belts to the southwest.

The foregoing discussion indicates the somewhat equivocal nature of some of the stratigraphic interpretations shown on Plate 1 in the Sylvia Lake-Cedar Lake marble. Nevertheless, the general form and continuity of this marble seems to be definitely established.

Structural Features of the Fullerville-Edwards Area

The pattern outlined by the units in the Sylvia Lake-Cedar Lake marble indicates that the northwesterly flank of the Sylvia Lake fold, which is overturned to the southeast, extends northeastward in unbroken continuity to the Cedar Lake-Edwards region. Near Edwards, the geologic relations, at first glance, would seem to indicate that this northwestern flank of the fold culminates in the Edwards fishhook fold, as defined in the median gneiss, and in the immediately older marble units to the north and east (Fig. 2; Pl. 1). Consequently, the Edwards fishhook fold in the gneiss and marble commonly has been thought of as the northeastern continuation of the same fold as that enveloping Sylvia Lake, although Brown's interpretation (1936) diverged considerably from this assumption. Certainly these two fold apices, at opposite ends of the district, appear to be connected by one well-defined flank. The moderate northeast plunge of the Sylvia Lake culmination of this inferred simple Balmat-Edwards fold and certain other features led Cushing and Newland (1925) to conclude that it was synclinal in form. Brown (1936, p. 240–244) reasoned that both Sylvia Lake and Edwards folds were second-order drags, formed along the flank of a major dome to the southeast. Probably neither hypothesis is complete and correct, although the Sylvia Lake fold almost surely is a segment of a syncline. Moreover, this syncline does trend into the Edwards area, but both stratigraphic and structural features there and elsewhere suggest that the

northeastern continuation of the Sylvia Lake syncline has been so tightly compressed that its trough (inferred to be crudely horizontal) is all but concealed within the median gneiss. The Edwards fishhook fold thus has to be a younger fold formed by refolding the isoclinal syncline along an axis essentially at right angles to that of the initial syncline. In effect, the data suggest that an accordant fold, the Sylvia Lake-Edwards syncline has been mashed tightly together in its northeastern portion, and subsequently refolded into a northwest-plunging cross fold.

Some of the important features that bear on this more complex interpretation of the geology around Edwards are the stratigraphic distribution and form of the (or a) rusty marble and the median gneiss, as these units are traced from Balmat into the Edwards area. Heretofore the median gneiss and any associated carbonate units that were mapped have been interpreted as simple homoclinally dipping units in the marble (Brown, 1936; Cushing and Newland, 1925; Gilluly, 1945). This interpretation still seems valid for the median gneiss and rusty marble in the southwestern half of the district. There, northeast of Balmat as far as the west branch of the Oswegatchie River, the median gneiss and rusty marble along the northwest side of the gneiss appear to form single, overturned units at the stratigraphic top of the Balmat section (Pl. 1). In this area they would, therefore, form a part of the uncomplicated, albeit overturned, northwest limb of the Sylvia Lake syncline. Unfortunately, in the next 1½ miles along the strike to the northeast, these and the associated marble units are covered by Pleistocene sand and silt. Northeast of the area of sand cover, along the projected strike, marble and what almost surely is median gneiss reappear north of the road junction, northeast of Fullerville (Fig. 1). As noted above, the marble in this area contains some of the stratigraphic units distinguished around Sylvia Lake and is regarded as continuous with the Sylvia Lake marble. The median gneiss at the road junction northeast of Fullerville has about the same composition as that farther southwest. It is appreciably thickened, complexly folded, but in part bent southward so that it appears to be offset to the south from that in the Balmat section. Presumably, this apparent offset, greater thickness, and what the writers interpret to be largely secondary changes in composition of the gneiss at North Fullerville led Gilluly (1945) to map this gneiss separately from the median gneiss to the southwest.

Repeated field and petrographic study of the geology in the area of the road junction northeast of Fullerville suggests that most of the gneiss there is an extension of the median gneiss in the Balmat section. The known and inferred relations are as shown in Figure 1. The folded and forked form of the gneiss, as well as the increased thickness there and northeastward, seems to reflect the abrupt convergence of opposite flanks of the Sylvia Lake syncline.

The convergence of flanks of the syncline northeast of Fullerville, or conversely, the flaring of the flanks of the structure to the southwest are best visualized by comparing Figure 1 with Plates 1 and 5. These relations seem to have been controlled by the form of the refractory amphibolite southeast of Fowler. The writers interpret the amphibolite to be a thick but tightly folded sill, injected into the marble immediately above the median gneiss before deformation of the Grenville Series (Pl. 5). The relative competency of this amphibolite sheet not only caused the marble around it to be thinned, but also seems to have prevented appreciable flattening of the core of the initial syncline in the area between North Fullerville and Balmat. Northeast of North Fullerville, however, no such competent unit exists within the syncline. Consequently, the flanks of the median gneiss appear to have been so completely mashed together, injected, and refolded that the axis of the syncline now is essentially concealed.

This interpretation seems to be substantiated by the distribution of rusty marble and other units on both sides of the gneiss to the northeast. Rusty marble is exposed on the north side of the thickened gneiss at the road junction northeast of Fullerville, but the south side of the median gneiss is covered. Locally, however, the rusty marble is absent on both sides of the median gneiss in the area between the road junction and Talcville. Conceivably the unit is squeezed out on both sides of the duplicated (?) gneiss. Northeast of Talcville a unit essentially

Explanation
Known
Readily inferred
Hypothetical
Unconformable deformation, crackled, brecciated, faulted rock
Strike and dip of bedding or oldest recognizable foliation in given exposure
Strike and dip of younger divergent foliation (commonly on basis pure foliation)
Plunge of crenulations and small folds
Plunge of larger folds (amplitude > 25 feet)
Plunge of subparallel elongate minerals or mineral aggregates
Traces of inferred axial surfaces of refolded synclines
State or township hard surface road
Inclined drill hole
Upper Cambrian (and lower Ordovician?)
Potsdam sandstone and siliceous breccia
Granite, gneissic, largely equigranular, biotitic (Hermon type)
Amphibolite, partly granitized gabbro, partly probably volcanic and carbonate paver rocks
Marble, undifferentiated, largely dolomitic, partly silicified, locally calcitic
Marble, undifferentiated, highly siliceous and silicated
Melon gneiss, quartz-two mica-feldspar-magnetite and amphibolite
Rusty marble, calcitic with diopside, mica, feldspars, tremolite, quartz and pyrite
Partly calcitic, partly dolomitic marble, silicated
Tremolite-anthophyllite-serpentine-talc schist, in part calcitic
Dolomite, slightly felid, locally diopsidic
Dolomite interlayered with diopsidic rock
Dolomite and silicated dolomite units 4-10, undifferentiated
Dolomite, locally silicated
Pyritic schist, quartz-mica-feldspar-chlorite-graphite
Basal dolomite, locally silicated
Quartz-biotite-oligoclase gneiss (migmatitic)
Precambrian
Grenville Series
Lower Cambrian
Paleozoic
Scale in feet
Oswegatchie River
Richards
Gouverneur
FULLERVILLE
N

FIGURE 1.—RECONSTRUCTION OF KNOWN AND INFERRED GEOLOGIC FEATURES IN THE AREA NORTH OF FULLERVILLE, N. Y.

This is in the central part of the Balmat-Edwards district, where the median gneiss seems to be mashed together along the axial plane of the Sylvia Lake Edwards accordant syncline. Note the folds in the trace of the inferred axial plane of this syncline. This refolding of the syncline is most apparent in the large drag folds that involve the median gneiss and amphibolite in the center of the area.

identical to rusty marble occurs on both the northwest and on the southeast sides of the gneiss (*see* Fig. 2). As this crudely symmetrical pattern of rusty marble is traced northeastward, a thin sheet of gneiss appears between it and the other units of older marble. The writers infer this interfingering of rusty marble and gneiss to be of sedimentary origin (Pl. 4, fig. 2).

It is pertinent that the rusty marble is sufficiently complex in composition to be almost unique as a stratigraphic unit in the Grenville series. Accordingly the repetition of what seems to be rusty marble on opposite sides of the thickened gneiss between Talcville and Edwards lends appreciable weight to the interpretation that the gneiss is duplicated in an isoclinal syncline. Certainly no two units of this type occur in areas of median gneiss that cannot be inferred to be duplicated.

The occurrence of more typical carbonate-rich marble as a medial lense in the gneiss at the apex of the fishhook fold (Fig. 2) constitutes still another reason for suspecting the repetition of median gneiss in the Edwards area. Assuming that the gneiss has been mashed together in the area between north Fullerville and Edwards, this apex of refolding would be the logical place to find any remnant of stratigraphically overlying marble caught between the flanks and along the axis of the initial isocline. Inspection of Figure 2 shows other interesting features in the pattern of median gneiss, rusty marble, and Sylvia Lake-Cedar Lake marble in the Edwards area. The Edwards fold is Z-shaped, with an abrupt termination of gneiss at the southeastern tip of the Z. There the opposed units of rusty marble converge and join in what appears to be the closure of the isoclinal syncline in the gneiss. This point, therefore, would seem to be the northeastern, opposite apex of the Sylvia Lake syncline.

In terms of stratigraphic synthesis, one of the most significant implications of the suggested isoclinal synclinal form of the median gneiss is that the marble southeast of the gneiss and at other places has to be part of the Sylvia Lake-Cedar Lake sequence. There seem to be no major metasedimentary units in the district other than quartz-biotite-oligoclase gneiss, Sylvia Lake-Cedar Lake marble, and median gneiss. Some of the marble associated with the Fowler amphibolite mass lies stratigraphically above the median gneiss, but the known thickness of this younger marble is little more than 200 feet.

The South Edwards area is a complex of marble and gneisses designated by numbers 4, 5, 6, 7, and 8 on Plate 5.

Two major features of this area would seem to demonstrate the general structural form of the metasediments. One is the large mass of quartz-biotite-oligoclase gneiss (hereafter the South Edwards gneiss and designated no. 8 on Pl. 5, shown only in small part on Pl. 1). The other feature is the contorted island of partly pyritic schist and gneiss (Pl. 5, 7), which lies in the marble midway between the South Edwards gneiss and the median gneiss. This partly pyritic island in the marble is referred to hereafter as the Pleasant Valley gneiss Except in some marginal slivers of pyritic schist (correlated with the pyritic schist of the Balmat section) around the Pleasant Valley gneiss, it and the South Edwards gneiss are interpreted as two grossly anticlinal parts of the same paragneiss. Brown (1936, Fig. 1 and p. 242) suggested this relationship, but concluded that this gneiss (his Lower Garnet gneiss) was older than the marble around and between it and the median gneiss, and also older than the quartz-biotite-oligoclase gneiss along the north and west margins of the district. Subsequent detailed study of the composition of the several garnetiferous gneisses (*see* Engel and Engel, 1953b), and the data pertaining to their form and field relations, indicate that the Pleasant Valley gneiss (Pl. 5, 7), the South Edwards gneiss (Pl. 5, between 6 and 9), and the quartz biotite-oligoclase gneiss at the base (northwest) of the Balmat section all are the same metasedimentary unit.

The anticlinal forms suggested for the South Edwards gneiss and Pleasant Valley gneiss imply a tight syncline in the marble between them (Pl. 5, 5). Plate 1 shows that this inferred syncline, as well as the anticlines in the gneisses, is much complicated by shearing out of beds and obscured by asymmetric cross folds analogous in orientation and presumably in origin to the Edwards fold.

Some of the known and readily inferred features of the Pleasant Valley gneiss (Pl. 5, 7) are

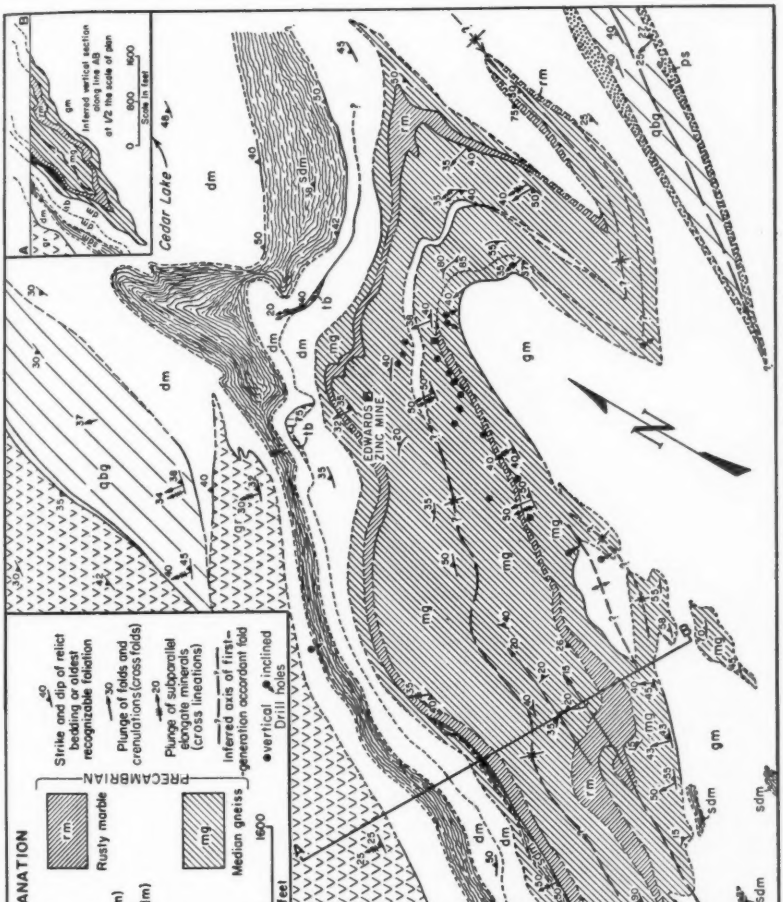

FIGURE 2.—GEOLOGIC MAP OF THE AREA NORTHWEST OF EDWARDS, N. Y.
Showing the inferred refolded form of the Balmat-Edwards syncline

shown in Figure 3. Specifically, its central portion consists of quartz-biotite-oligoclase gneiss, which seems to protrude upward as the apex of a refolded anticline. The inferred anticlinal fold presumably was a northeast-trending isocline, the analogue of the mashed synclinal isocline in the median gneiss to the north. It should be emphasized that the initial accordant fold is blurred or obliterated at most points by superimposed cross folds of the Edwards type. These cross folds are the dominant structural features visible in this area. The much disrupted fragments of pyritic schist shown peripheral to the Pleasant Valley gneiss (Fig. 3) are believed to be the same pyritic schist as unit 2 in the Balmat section. Pyritization is by no means confined to these peripheral slivers, however, but pervades much of the gneiss. The large areas of pyritization within what the writers interpret as the quartz-biotite-oligoclase gneiss in this area led Gilluly (1945) to correlate the entire Pleasant Valley gneiss with the pyritic schist around Sylvia Lake, but this interpretation seems contradicted by the mineralogical and chemical composition of the gneiss.

The suggested syncline in the marble between the Pleasant Valley gneiss and the South Edwards gneiss (Pl. 5, 5) also would have to be refolded as are the accordant folds in the gneiss to the north. The features that suggest this interpretation are highly analogous to those already described. In the marble (Pl. 5, 5), segments of what seems to be the median gneiss, rusty marble, and siliceous dolomite units (4 and 6?) appear in patterns that could represent parts of an isoclinal syncline. But the axis of any such syncline must have a northeast trend and be grossly accordant to the axes of the mashed and blurred accordant folds in the Pleasant Valley gneiss and in the median gneiss.

In all these places, the detailed stratigraphic and structural relations seem most consistent with the interpretation of two generations of folds. That is, the blurred axes and apical parts of pre-existing accordant folds seem to be

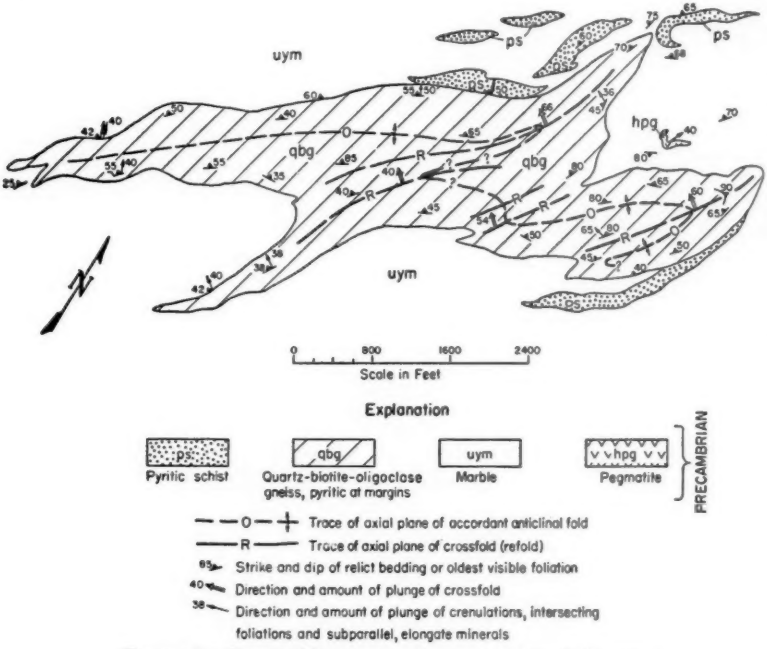

FIGURE 3.—SKETCH MAP OF THE PLEASANT VALLEY GNEISS
Showing the inferred relations of accordant and cross folds

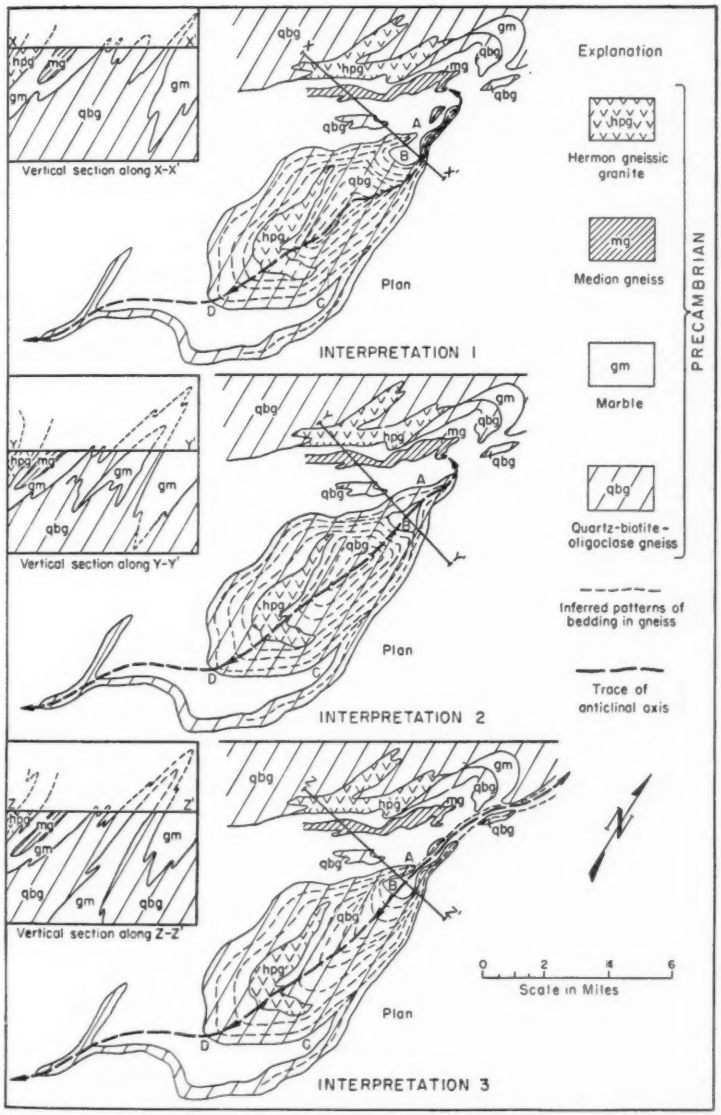

FIGURE 4.—DIAGRAMMATIC SKETCHES OF THE QUARTZ-BIOTITE-OLIGOCLASE GNEISS IN THE VICINITY AND SOUTH OF EDWARDS, N. Y.
Showing three possible interpretations of its structural form

grossly horizontal, and thus nearly at right angles to the axes of the cross folds.

The broad structural form of the South Edwards gneiss is undoubtedly anticlinal or domical as Cushing and Newland (1925) noted (*see* Fig. 4). The southwest half of the mass verges on a simple, broadly rounded, accordant fold, although its plunge is fairly steep (50°) to the west-southwest. The northeastern end of the South Edwards gneiss is, however, far from

simple. Cushing and Newland (1925, p. 58–62) concluded that the northeast end of the gneissic "dome" was a "closely pinched anticline which pitches north." They believed that the two large northeast-trending tongues of the gneiss (Fig. 4B; Pl. 1, southeast corner; Pl. 5) were two anticlines separated by a synclinal mass of marble (*see* Cushing and Newland, 1925, Figs. 6, 9, and 11). The southeastmost tongue of gneiss was assumed to be the parent anticlinal fold, and the northwestern tongue was regarded as a subsidiary anticline.

In generalized form this interpretation now is preferred by the authors (Fig. 4, interpretation 1), but only after having courted several hypotheses. If these gneiss prongs do represent subsidiary and major anticlinal folds, however, they are accordant structures, now largely obliterated and sheared out by cross-folding motions.

A second hypothesis, suggested by Brown (1936, Fig. 1 and p. 236), was prompted by certain field data that seem to indicate that this marble at 6 (Pl. 5) is the squeezed residue of a pre-existing carbonate interbed in the gneiss, now forced into the northeastern apex of an anticlinal nose in the gneiss (Fig. 4, interpretation 2; *see* point B). If these relations pertain, the large prongs of gneiss (Fig. 4,B; Pl. 1, southeast corner; Pl. 5, 6) would seem to represent the opposite, outermost flanks of a single northeastern apex of the dome in the gneiss. The gneissic prongs were assumed by Brown (1936, p. 236; Fig. 1) to be connected at their northeast ends and thus to envelop the large intervening tongue of marble.

In many respects this is the simplest explanation of the major features involved. Certainly the southwestern part of the gneiss (Fig. 4,D; Pl. 5, southwest of 9) seems to be an opposite, anticlinal nose plunging 45° SW. And a crudely analogous area of marble appears there near the top of the gneiss.

All the features in the gneiss northwest of 9 (Pl. 5) cannot be reconciled with this explanation. In the first place, the juncture of the two prongs of gneiss (Pl. 5, just north of 6) as suggested earlier by Brown (1936, Fig. 1; p. 236) must be inferred, for in this area the bedrock is covered with alluvium. Moreover, the layers (beds?) of gneiss just southwest of 6 on Plate 5 (*see* details on Pl. 1) seem to form a northwest-plunging fold whose apex or convex side faces southwest (Fig. 4, interpretation 3). The same general pattern of a cross fold convex to the southwest seems to persist throughout the area between 6 and 9 (Pl. 5). Consequently, the attitude of the layering suggests that the prongs of gneiss at 6 (Pl. 5) may be the greatly thinned flanks of a single cross fold. The change in direction and amount of plunge of this fold from its seeming core (Pl. 5, 6) to its apex (Pl. 5, 9) would be induced by a progressive decrease in the dip of the layers at and near the axial plane of the fold as the axis is followed southwest into successively younger (southwestern) horizons in the gneiss.

If the axis of a singly plunging fold of this type is projected upward from the earth's surface to the northeast and arched downward again into the quartz-biotite-oligoclase gneiss northeast of Edwards (Pl. 5, north of 10), it could be related to an anticlinal fold in the gneiss there.

In each of the several hypotheses pertaining to the form of the South Edwards gneiss, the marble at point 6 (Pl. 5) plays an important and interesting role. As noted in the discussion of interpretation 1 (Fig. 4), the marble at 6 (Pl. 5) is inferred to be a part of the Sylvia Lake-Cedar Lake area. In interpretation 2 (Fig. 4), this marble is inferred to represent an interlayer near the top of the gneiss; and in interpretation 3 (Fig. 4), it is suggested to be a hybrid type but composed largely of marble that is stratigraphically below the gneiss. This lower marble presumably would be the central or Gouverneur marble belt noted in the earlier section on Regional Setting.

One of the reasons for assuming a marble interlayer in this gneiss as noted in interpretation 2, above, lay in the relationship of marble and gneiss east of Trout Lake (Pl. 5, 3). The marble in that area seemed to be an independent zone interlayered in the gneiss. However, a restudy of this marble resulted in the discovery in it of slivers of what seem to be median gneiss, pyritic schist, and other units of the Sylvia Lake-Cedar Lake marble. The distribution of these stratigraphic units suggests that the marble at 3 (Pl. 5) forms the remnant of a shallow accordant syncline, separated from the

Sylvia Lake-Cedar Lake marble by a complementary accordant anticlinal fold in the gneiss (Pl. 5, 2). Both of these accordant folds evolved with the isoclinal syncline in the median gneiss, and were refolded with it during the evolution of the Edwards cross fold.

All the cross folds in the Edwards area, including the one postulated in the South Edwards gneiss in interpretation 1 (Fig. 4), have the forms of gigantic drag folds, with a common direction sense. Inasmuch as the southeast flanks of these folds are relatively short, recurved, and partly disrupted, it may be inferred that their northwest, longer flanks have been dragged northeastward. In effect, the relations are those which could have been induced by a major force couple acting along northeast-southwest lines. The planes of shear (foliation) resulting from this couple dip northwest, and the axes of the cross folds lie in these planes and plunge northwest. Consequently, the plane of the inferred couple dips southeast.

Both the stratigraphic and structural features in the Edwards area indicate that large displacements—several miles or more—were involved during the cross folding processes and localized in the zone between the South Edwards and the median gneisses. Certainly the disruptions in the stratigraphic units in this zone seem to require lateral displacements on the order of 1 to 3 miles. Equally large and pervasive movements also would seem to be required to permit the growth of the larger cross folds in the gneisses. Presumably the direction of maximum shear was normal to the axes of cross folding and parallel to the trend of the dominant foliation. This orients the direction of net slip northeast-southwest roughly parallel to the earth's surface.

Structural Features in the Balmat Area

General statement.—Apropos of the direction and kinds of rock motions to be inferred from the cross folds and related features in the Edwards end of the district, it is instructive to examine the structural features in the Balmat area, especially the Sylvia Lake fold, the California phacolith, and the Balmat fault.

Sylvia Lake syncline.—The detailed form of the fold around Sylvia Lake (Pl. 2) definitely is not that of a simple fold. Its broad form as noted earlier is synclinal, the southwestern culmination of the same accordant isoclinal syncline inferred to extend from Sylvia Lake to Edwards. The trace of the axial plane of this accordant syncline in the vicinity of Sylvia Lake is shown by the dashed line through the points 1, 2, 3, 4, and 5 (Pl. 2). At point 1 (Pl. 2), the flanks of the syncline, as defined by metasediments, flare around the folded Fowler metagabbro sill. To the southwest, however, between the points 2, 3, 4, and 5 (Pl. 2), the marble on opposite flanks of the syncline is fused together and refolded. The refolding is most apparent along the axis of the syncline between points 3 and 4 (Pl. 2), where the initial syncline is rolled clockwise to the northeast. The rolling or refolding motion took place along axes that plunge gently north, or locally northeast. The resulting folds are draglike structures with essentially the same form and direction sense as the cross folds in the eastern half of the district. That is, their axial planes have a south to southwestern trace, and the southeast flanks of the anticlinal folds are short and commonly disrupted or attenuated as compared to their northwest flanks (Pl. 3, Fig. 2). Inasmuch as certain of these folds involve both flanks of the initial syncline and have a common direction sense, they clearly are superimposed upon the initial syncline. Comparison of these second-generation draglike folds with those to the northeast indicates that all are the products of the same couple. Some of the smaller folds of this type are shown in Plates 3 and 4. The drag folds involving median gneiss, amphibolite, and other units north of Fullerville (Fig. 1) are interpreted as much less obvious examples of refolds in the pre-existing Balmat-Edwards syncline in the area where it is mashed flat. There are many smaller and less obvious drag folds in other areas between Sylvia Lake and Edwards. The axes of the drag folds tend to converge slightly downdip to the northwest, so there is a subtle transition from the northward-plunging drags around Sylvia Lake to the northwest-plunging types in the Edwards area (Pl. 1). Fold and shear displacements equal in kind and direction sense to those indicated around Sylvia Lake also are present in a zone along the south side of the Sylvia Lake syncline,

between it and the north side of the California anticline.

California anticline (phacolith).—The California anticline is a phacolithic mass of alaskitic granite in quartz-biotite-oligoclase gneiss, as Buddington pointed out (1929, p. 61–65). Presumably this structure (Pl. 5, 14) had its inception as an accordant anticline, intertonguing with the Sylvia Lake syncline on the north and the small syncline (Pl. 5, 13) in the marble between the California anticline and the South Edwards anticline. The axis of the California anticline, however, is now markedly arcuate upward, although its axial plane is not obviously refolded. The arcuation of the fold axis is asymmetric to the northeast. Thus the southwestern nose of the California anticline plunges gently (15°–25°) southwest, parallel to the accordant folds northwest of it in the central part of the Grenville Lowlands. The northeastern nose of the California anticline plunges at a much steeper angle (45°–65°) to the north-northeast. In addition, smaller draglike folds and closely related linear elements along the northern side of the anticline plunge northward, parallel to the refolds in the Sylvia Lake syncline. Seemingly these northward-plunging cross folds and the steepened northeastern nose of the California anticline were formed during and by the cross-folding motions, for the forms as well as the orientation of many of the drag folds on both flanks of the anticline are like those to the north and east.

Balmat fault zone.—The northeast-trending zone of complexly sheared and crackled rocks between the California anticline and the Sylvia Lake syncline is designated the Balmat fault zone (Pl. 1). This zone is one of profound solid flow and rupture of the rocks. A stratigraphic and structural discontinuity along this zone was suggested first by Smyth and Buddington (1926, p. 96) and described later by Brown (1936, p. 243–244) as the Balmat fault. Actually, much of the seeming stratigraphic discontinuity in this zone (Pl. 1) is probably like that noted in the Edwards area. That is, the major disruptions were produced during solid flow and recrystallization of the rocks. But in the Edwards area and in most other parts of the district, large and obvious zones of rupture are not superimposed upon the surfaces of flow, hence the displacements are not specifically designated or mapped as faults, but merely surfaces and zones of shear or flowage (foliation, schistosity).

As Brown (1936, p. 243–244) noted, however, there is ample field evidence of a well-defined northeast-trending zone of fractured, cataclastic rock as much as several hundred feet wide just south of Kellogg Corners and Balmat village (Pl. 1). This fault zone parallels the major zones of shear formed by the cross-folding motions and it is tempting to relate its origin to a final stage of the cross folding. Good exposures of this fault zone do not exist, however, and its exact nature remains speculative. The exposures of crackled rock along the margins of the zone suggest a belt of faulting and brecciation that only partly coincides with and is superimposed upon the dominant foliation and flowage in both metasediments and phacolithic granite. Certainly the cataclastic deformation is younger than the igneous-looking rocks, for it cuts off and brecciates both the California phacolith and the inequigranular Hermon-type granite west of Fullerville.

The relations along the fault may be rudely comparable to those that might result if a southwest-trending crackled zone like the Balmat fault zone were superimposed upon the Edwards "shear zone". Even though there was no further displacement in the Edwards area as a result of the brecciation, a large fault displacement might mistakenly be inferred.

The lack of exposures of the "fault" surfaces prevent detailed analysis of the displacements involved during cataclasis. Nor are there well-defined, subsidiary ruptures or drag folds on either side of the main zone correlative with the rupturing to indicate motion patterns. The ruptures seem to form a thrust that dips northwest at moderate angles (35°–50°) and involves a maximum net slip of perhaps 200–1000 feet, in a direction near the dip. Either thrusting up dip, or strike-slip motions (northwest side to the northeast) of some 400–1500 feet could account for the lithologic discontinuities caused by rupturing.

Some Regional Implications of the Refolding Hypothesis

If refolding is one of major significance in the evolution of cross folds in the Balmat-Edwards

district, other cross folds in the belt so characterized probably have a smiliar origin. Just northeast of the district, for example, in the northern part of the Russell quadrangle (Buddington and Leonard, in manuscript) and in the Canton quadrangle (Martin, 1916) quartz-biotite-oligoclase gneiss and marble contiguous with that in the district are involved in a series of spectacular cross folds. These folds bear much the same relation to regional structure and stratigraphy as do the cross folds of the Balmat-Edwards district. They are also asymmetrical in the same direction sense as the cross folds between Balmat and Edwards, and are undoubtedly products of the same deformation. Martin was the first to recognize the general forms of these large northwest-plunging folds. He also speculated upon their origin: possibly through (1) tilting, (2) a complex triaxial deformation, or (3) successive deformations (1916, p. 93–108). In summing up Martin noted:

"It is not meant to imply, however, that the disturbances which produced such a tilted isocline [cross fold] as that described in this report were necessarily distinct in time or direction [from those which induced accordant folds] though this is difficult to disprove. Various stresses acting simultaneously could have resulted in a deep-seated torsional strain, whose end product would be the same as that caused by a succession of distinct and discordant compressions."

Refolding *per se* was not discussed by Martin, although the concept is implicit in some of his report. The hypothesis of refolding also is entirely consistent with the regional studies of Buddington (1929, p. 53, 67, 77; 1934, p. 138–171; 1939, p. 238–243). In discussing the orogenic history of the Grenville Lowland region, Buddington (1939, p. 243) concluded that two periods of deformation occurred, with an intervening, less deformative, period of granitic intrusion. He noted that during the second deformation "the rocks of the Grenville belt were further deformed, most intensively on each border in such a fashion that the material was pressed up and out over the underlying igneous rock."

Much additional evidence of two deformations in the region immediately east of the Balmat-Edwards district recently has been obtained by Buddington and B. F. Leonard (in manuscript). In this unpublished work Buddington summarizes as follows:

"The discussed inconsistencies between the nature of the metamorphism of the quartz-syenitic rocks and the younger granitic series in the same geographic belts is in accord with the hypothesis based on structural relationships that the quartz syenitic complexes and older formations were folded and metamorphosed before the intrusion of the younger granitic rocks. Since the latter are in part also metamorphosed, there must have been in effect at least two major periods of deformation and metamorphism."

In the same report, Leonard also describes in detail two sets of fold axes in the area of the Clifton magnetite mine. He concluded that these are products of two separate periods of deformation. Consequently cross folding appears to exist at Clifton, which is just south of Degrasse, New York, about 10 miles east of Edwards village.

The existence of a second belt characterized by steeply plunging folds along the northwest side of the Grenville Lowlands was first discussed by Buddington (1929, p. 82–86; 1934, p. 138–171). This belt includes the Rossie, Hammond, and Black Lake areas, and represents the northwestern boundary zone between the Grenville Lowlands and the great granite masses of the Gananoque-Brockville-Mallorytown areas (*see* Buddington, 1939, Fig. 25 and Pl. 21; Engel, 1948, Fig. 1). In many respects the structural features there are analogous to those along the southeastern zone of cross folding, which includes the Balmat-Edwards district. Consequently, the regional pattern would seem to include a central zone of accordant folds bordered on either side by more steeply plunging cross folds. Both of the zones characterized by cross folds merge on their outer sides into great batholithic masses in which metasediments of the Grenville series are complex, minority elements.

It should be noted that the northwest contact of the Grenville series with the igneous rocks of the Gananoque-Mallorytown region dips steeply. Consequently, the cross folds in this region plunge near the vertical. This in no way alters the possibility (probability?) that the cross folds on either side of the lowlands belt have a common or closely related origin.

Whether all or most of the steeply plunging folds along the northwest side of the Grenville Lowlands have the same direction sense as those in the southeastern belt of cross folds is not known. Nor have examples of refolding been recognized to the northwest. These and many other problems of the region would seem to be soluble, however, through careful, detailed mapping. It is upon such mapping that a broader synthesis must be built.

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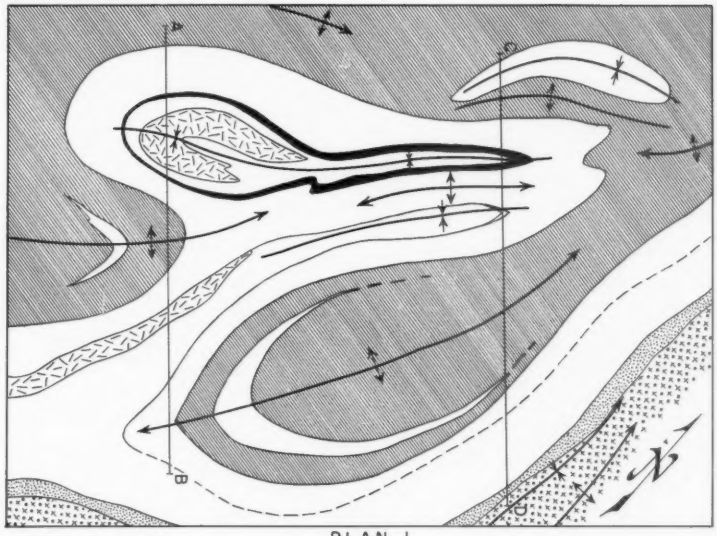


PLAN I

EXPLANATION

Syenitic gneisses

Amphibolite

Feldspathic quartzite

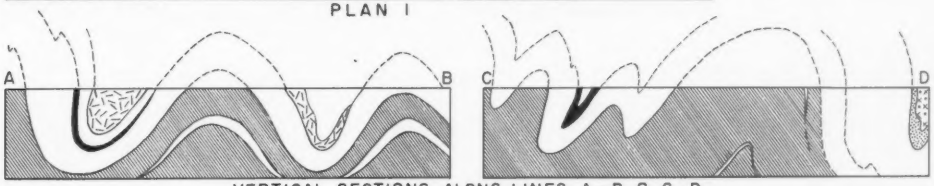
Marble (white) with Median gneiss (black)

Quartz biotite gneiss (marble lenses)

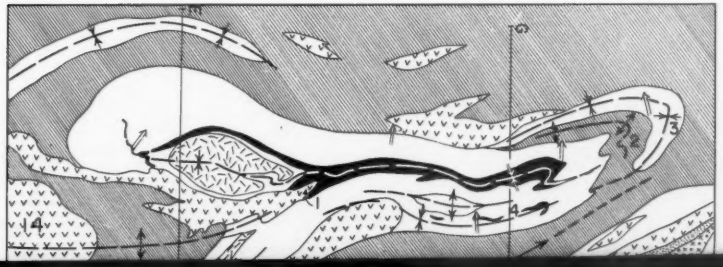
Precambrian

Axis of syncline

Axis of anticline



VERTICAL SECTIONS ALONG LINES A–B & C–D

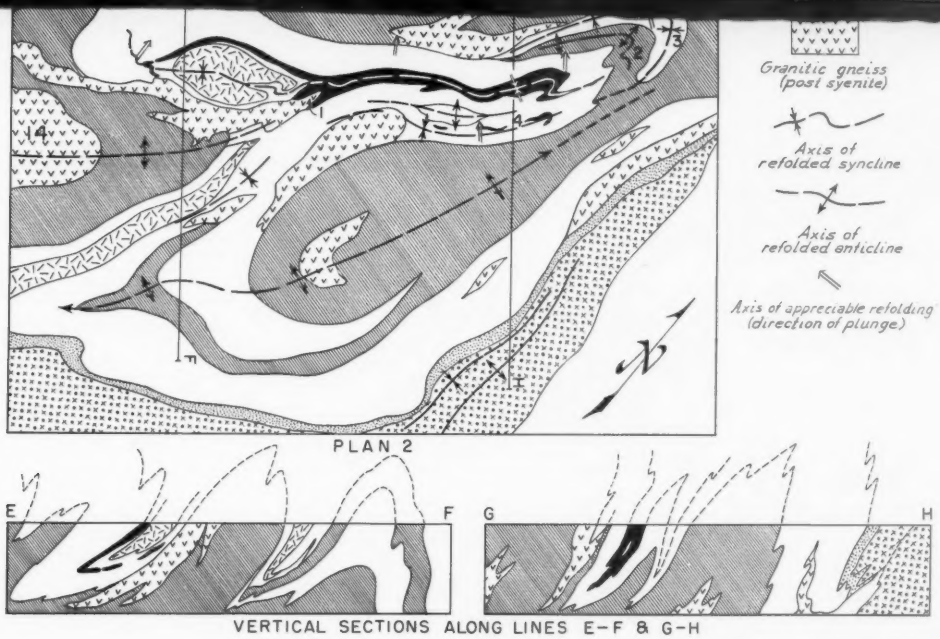


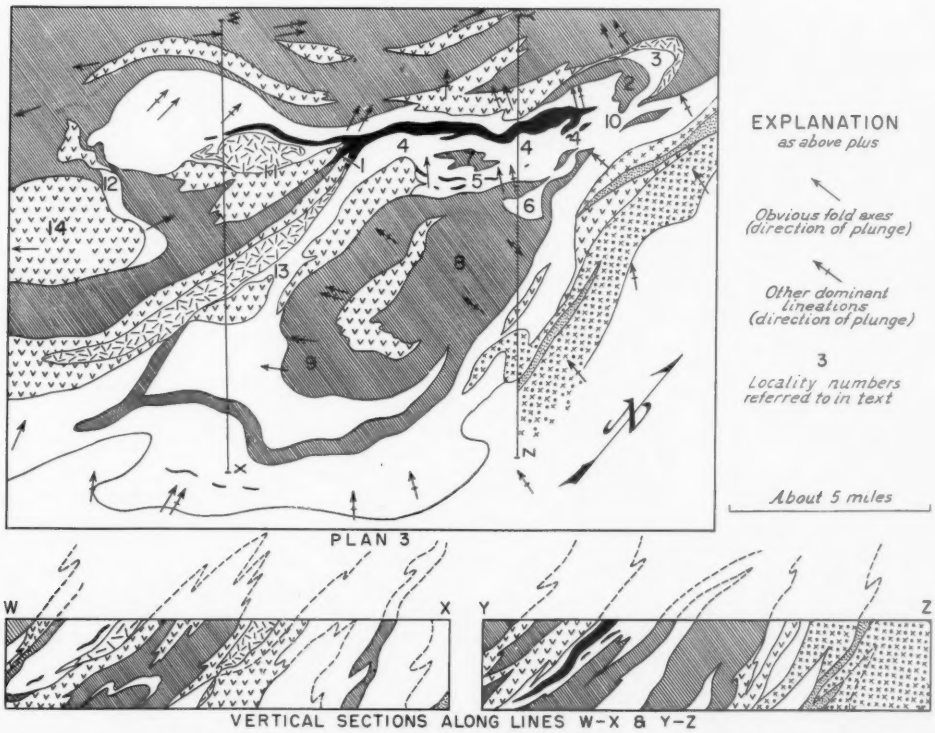
EXPLANATION

as above plus

Granitic gneiss (post syenite)

Axis of refolded syncline





DIAGRAMMATIC SKETCHES ILLUSTRATING INFERRED DEVELOPMENT OF STRUCTURAL FEATURES IN THE BALMAT-EDWARDS DISTRICT

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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SEISMIC-REFRACTION STUDIES OF THE PACIFIC OCEAN BASIN

PART I: CRUSTAL THICKNESS OF THE CENTRAL EQUATORIAL PACIFIC

BY RUSSELL W. RAITT

ABSTRACT

On the MID-PACIFIC and CAPRICORN expeditions seismic-refraction observations were made at 42 stations scattered widely within an area of the Central Equatorial Pacific Ocean extending from latitudes 22° S. to 28° N. and longitudes 162° E. to 112° W. At 29 of these stations velocities of about 8 km/sec. or more were reached at the depth of greatest penetration of the refracted waves. The mean of these velocities was 8.24 km/sec.

The crustal thickness, defined as the depth below the sea floor at which the 8 km/sec. velocity is reached, ranges from 4.8 km to 13.0 km. The distribution of thicknesses is bimodal with seven anomalous stations giving values between 10 and 13 km. The group of 22 stations believed to be typical of the deep Pacific Basin has an average thickness of 6.31 km with a standard deviation of 1.01 km.

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INTRODUCTION

Since the fall of 1948, seismic-refraction studies of the Pacific Ocean bottom have been made in a region extending from San Diego to the Marshall Islands and south almost to the Tropic of Capricorn. The work includes several types of problems and is separated roughly into three geographic regions: (1) the deep Pacific Basin proper; (2) atolls and islands; (3) the continental margin of North America and Central America. The present paper contains

some results in category (1) obtained on two expeditions into the Central Equatorial Pacific: the MID-PACIFIC expedition of 1950 and the CAPRICORN expedition of 1952–1953 (Revelle, 1954).

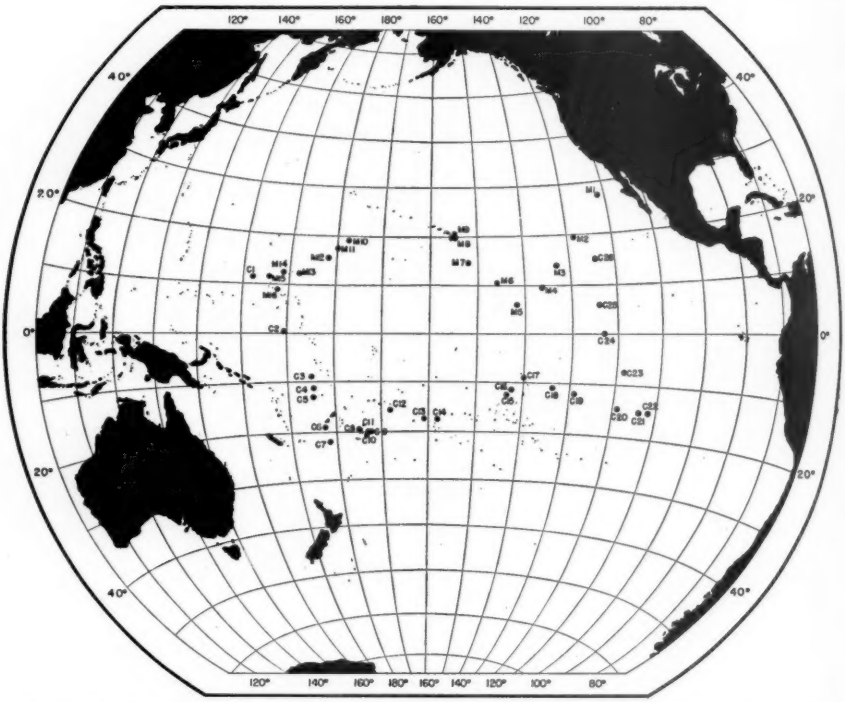

FIGURE 1.—SEISMIC-REFRACTION STATIONS OF THE MID-PACIFIC AND CAPRICORN EXPEDITIONS

ACKNOWLEDGMENTS

A seismic-refraction program of the magnitude of that conducted on the MID-PACIFIC and CAPRICORN expeditions requires the help of many people.

The leader of both expeditions was Roger Revelle, Director of Scripps Institution of Oceanography. His interest and help throughout the work at sea, as well as in the analysis of the data, were major factors in its success.

The officers and crew of the USS EPCE(R) 857, R/V HORIZON and R/V SPENCER F. BAIRD were of great help in all phases of the sea operations. The commanding officers of 857 and HORIZON on the MID-PACIFIC expedition were Lt. Comdr. D. J. McMillan (USN) and James L. Faughn, respectively. The commanding officers of HORIZON and BAIRD on the CAPRICORN expedition were Noel L. Ferris and Laurence E. Davis.

On the MID-PACIFIC expedition, Daniel K. Gibson supervised the firing operations, assisted by Chief Gunner's Mate Albert Obregon. On the CAPRICORN expedition, Willard C. North supervised the firing operations, and Maxwell Silverman of U. S. Navy Electronics Laboratory was in charge of the firing of explosives, assisted by Edward J. Taylor.

Members of the recording and firing groups were Jeffery D. Frautschy, Edwin M. Hamilton, Richard P. von Herzen, Winter D. Horton, Jr., Alan C. Jones, A. D. Raff, T. Wayne Runyan, Richard J. Smith.

The travel-time data were read, plotted, and analyzed by Gloria J. Slack, Gwendolyn A.

Roy, Clara B. Crane, Shirley R. Shivers, and Frieda K. James.

Valuable suggestions for improvements of the manuscript were received from M. N. Bramlette and George G. Shor, Jr. of Scripps Institution of Oceanography, and from M. N. Hill of Cambridge University.

TABLE 1.—MID-PACIFIC STATIONS

Station	Date, 1950	Latitude, N.	Longtitude	Sea depth in m
M1	29 July	27° 24′	121° 35′ W.	4176
M2	2 Aug.	19° 22′	128° 30′ W.	4829
M3	6 Aug.	13° 46′	133° 41′ W.	4908
M4	9 Aug.	9° 38′	136° 19′ W.	4804
M5	13 Aug.	5° 51′	141° 51′ W.	4811
M6	16 Aug.	10° 43′	145° 53′ W.	5249
M7	19 Aug.	14° 41′	151° 54′ W.	5797
M8	21 Aug.	20° 02′	155° 11′ W.	338
M9	22 Aug.	20° 26′	154° 54′ W.	5199
M10	16 Sept.	19° 02′	177° 19′ W.	4833
M11	17 Sept.	17° 20′	179° 58′ W.	4929
M12	19 Sept.	15° 34′	177° 40′ E.	4200
M13	21 Sept.	12° 39′	172° 10′ E.	5547
M14	22 Sept.	12° 27′	168° 22′ E.	4927
M15	8 Oct.	11° 12′	165° 10′ E.	4458
M16	1 Oct.	8° 55′	167° 41′ E.	42

STATION LOCATIONS

The locations of all the areas where seismic-refraction work was done on MID-PACIFIC and CAPRICORN expeditions are shown in Figure 1. Latitudes and longitudes of the approximate centers of the working areas are tabulated in Tables 1 and 2. MID-PACIFIC stations are prefixed with the letter M, and CAPRICORN stations with the letter C. Four areas, M8, M16, C4, and C17 represent shallow-water studies in the vicinities of the Island of Hawaii, Kwajalein Atoll, Alexa Bank, and Nukuhiva Island, respectively. They are not included in the present study. Two areas, M15 and C1, were the sites of extensive refraction observations in both shallow and deep water at Bikini and Eniwetok

TABLE 2.—CAPRICORN STATIONS

Station	Date	Latitude	Longitude	Sea depth in m
C1	20 Nov. 1952	11° 20′ N.	161° 35′ E.	3862
C2	2 Dec.	00° 47′ N.	169° 11′ E.	4414
C3	6 "	9° 01′ S.	174° 56′ E.	5171
C4	9 "	11° 34′ S.	175° 24′ E.	31
C5	10 "	13° 36′ S.	174° 56′ E.	2463
C6	18 "	18° 59′ S.	177° 34′ E.	2617
C7	20 "	21° 55′ S.	178° 33′ E.	4134
C8	28 "	19° 37′ S.	174° 54′ W.	1740
C9	30 "	19° 57′ S.	172° 33′ W.	6099
C10	1 Jan. 1953	20° 30′ S.	173° 20′ W.	9176
C11	2 "	20° 02′ S.	173° 07′ W.	8860
C12	10 "	16° 16′ S.	168° 31′ W.	5137
C13	13 "	17° 28′ S.	160° 59′ W.	4850
C14	14 "	17° 32′ S.	158° 40′ W.	5212
C15	22 "	12° 47′ S.	143° 33′ W.	4624
C16	23 "	11° 20′ S.	142° 25′ W.	4590
C17	25 "	8° 57′ S.	140° 01′ W.	77
C18	28 "	10° 45′ S.	133° 35′ W.	4188
C19	30 "	11° 46′ S.	128° 57′ W.	4073
C20	2 Feb.	14° 16′ S.	119° 10′ W.	3575
C21	4 "	14° 59′ S.	113° 46′ W.	2915
C22	5 "	14° 47′ S.	112° 12′ W.	3155
C23	8 "	7° 20′ S.	118° 40′ W.	4330
C24	11 "	00° 11′ N.	123° 26′ W.	4463
C25	13 "	5° 47′ N.	123° 59′ W.	4264
C26	16 "	14° 58′ N.	124° 12′ W.	4393

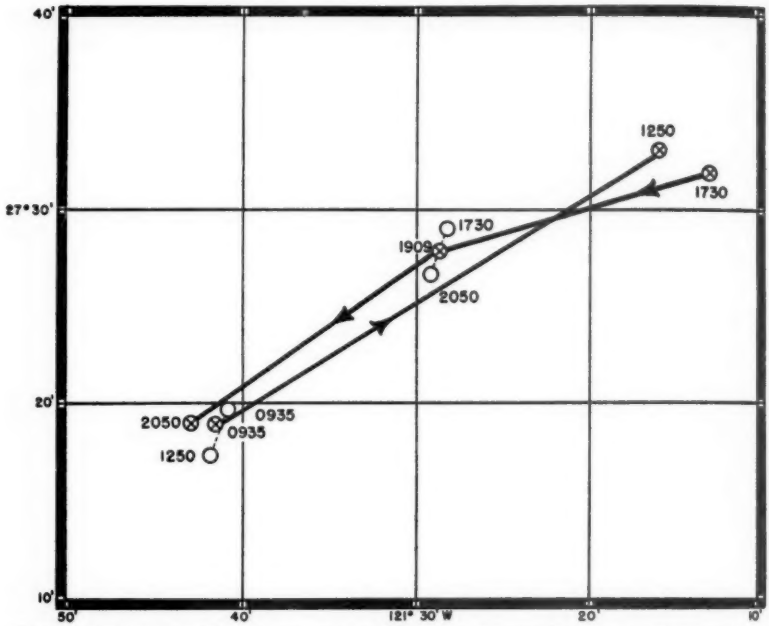

FIGURE 2.—PLAN OF OPERATIONS OF THE REVERSED SEISMIC PROFILE AT STATION M1, JULY 29, 1950

○- - - -○ Drift track of receiving ship
⊗——⊗ Track of firing ship

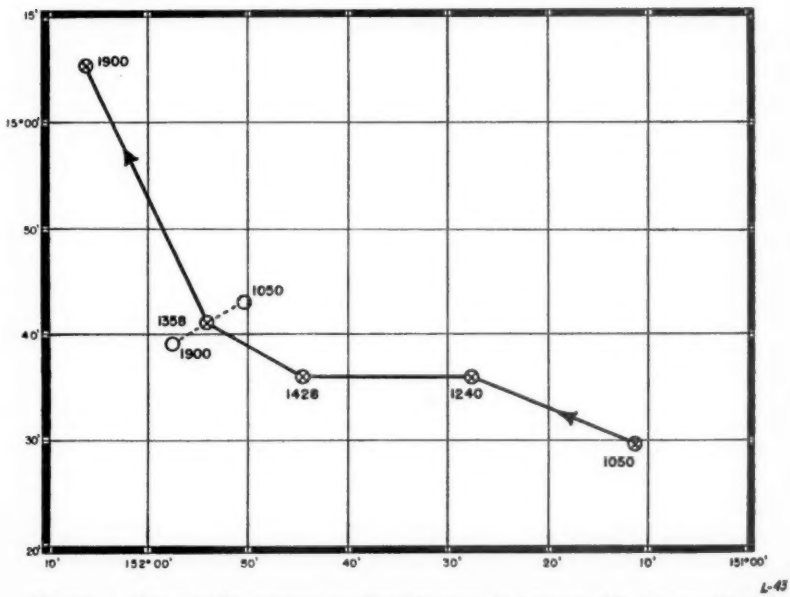

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FIGURE 3.—PLAN OF OPERATIONS OF SPLIT PROFILE AT STATION M7, AUGUST 19, 1950

○- - - -○ Drift track of receiving ship
⊗——⊗ Track of firing ship

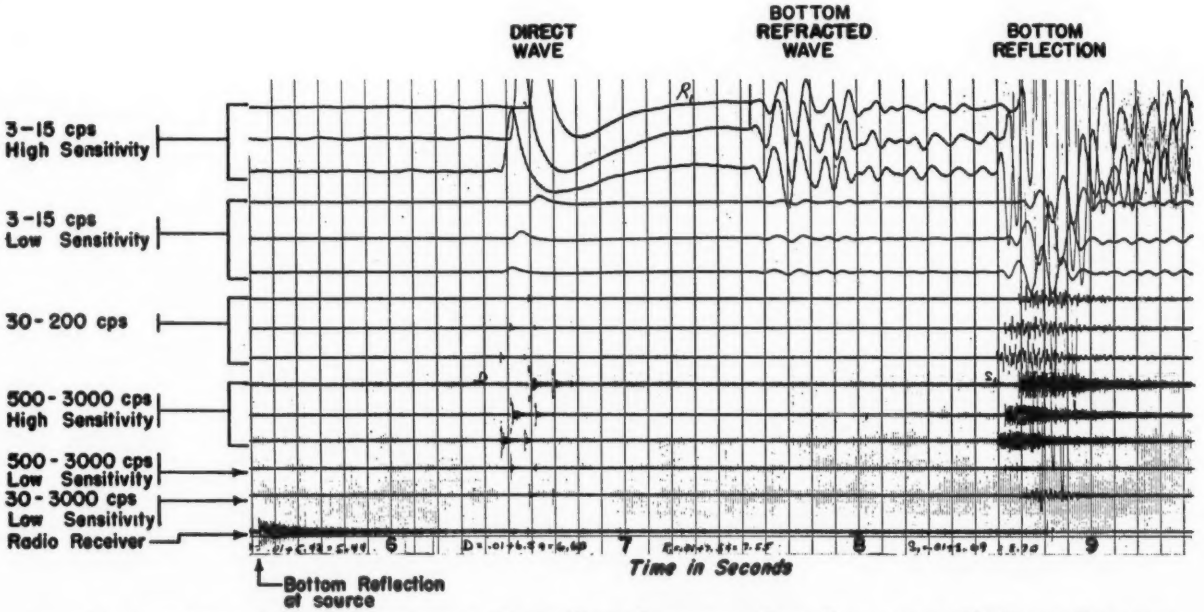

FIGURE 4.—SAMPLE OF A COMPLETE OSCILLOGRAM OF SEISMIC WAVES RECORDED AT SHORT RANGE ON THE MID-PACIFIC EXPEDITION
Length of three-hydrophone spread—600 feet
Charge—3½ pounds TNT
Shot distance—5.5 nautical miles
Ocean depth—2255 fathoms

atolls. The complete results from these two areas are reported elsewhere (Raitt, 1954; in press). In the present study, only the deep-water data observed near Bikini and Eniwetok are included. Stations C8, C9, C10, and C11 are in the Tonga area and are included in a separate study of the Tonga Trench (Raitt, Fisher, and Mason, 1955). Two other stations were near islands: M9, near the Island of Hawaii, and C6 near Viti Levu in the Fiji Islands.

The remaining 30 of the 42 stations were distributed along the course of the expeditions in positions away from islands or island groups. Efforts were made to locate these positions in flat areas in order to free the measurements from the perturbations of rough topography. These efforts, however, were rarely successful, owing to the rough bottom generally found in the Pacific and to the paucity of prior soundings in the regions explored.

Operations

At all stations two ships were used. On the Mid-Pacific expedition, USS EPCE(R) 857 served as firing ship throughout the operation, and R/V Horizon was the receiving ship. On the Capricorn expedition, R/V Horizon was the firing ship, and R/V Spencer F. Baird was the receiving ship.

Two types of seismic runs were recorded, reversed profiles (Fig. 2) and split profiles (Fig. 3). Open circles and dashed lines indicate the line of drift of the receiving ship R/V Horizon; the crossed circles and solid lines show the lines run by the shooting ship, USS EPCE(R) 857, at a speed of 9 knots. The operation represents an attempt to record a true reversed profile in which charges are fired along a single line through two receiving positions. Failure to achieve true reversal is caused partly by wind- and current-induced drift of the receiving and sending ships and partly by poor navigational control which depends primarily on star fixes made several hours before or several hours after the operation.

Where receiving ships can be anchored and good position control can be achieved, reversed profiles are used to good advantage (Raitt, 1954). In the deep sea, however, the firing lines rarely coincide and much of the value of the reversal is lost. It is nearly as accurate and gives greater coverage to record a split profile. Many more split profiles than reversed profiles were recorded in the study here presented.

The sources of the seismic waves were TNT bombs made up from demolition charges, in

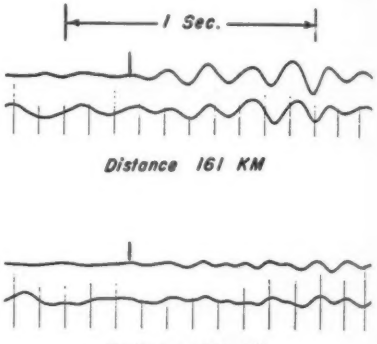

Figure 5.—Sample Oscillograms of the Low-Frequency Seismic-Refracted Waves Recorded at Long Range

sizes commonly between half a pound and 80 pounds. A few larger charges up to 450 pounds were fired. The charges were dropped while the firing ship was under way and were fired at a predetermined depth between 100 and 200 feet with slow-burning fuse cut to appropriate length.

The waves from the shots were received on pressure-sensitive hydrophones suspended from surface buoys at a depth of about 200 feet. They were recorded photographically on a multichannel oscillograph with several bands of frequencies for each hydrophone. The filters were chosen not only to enhance the refracted-wave record but also to aid in identifying the waterborne sound used to determine shot-hydrophone distances. Velocities for the latter purpose were read from Kuwahara's (1939) tables, using temperatures and salinities measured in the locality of the observations. Timing accuracy of the oscillograph was checked frequently by comparison with WWV time signals.

An example of the kind of record obtained at short range is shown in Figure 4. It was recorded during the Mid-Pacific expedition, on which three hydrophones were used for most shots. On the Capricorn expedition, four hydrophones were used, but the filtering arrangements were similar.

As the range is increased, the bottom-re-

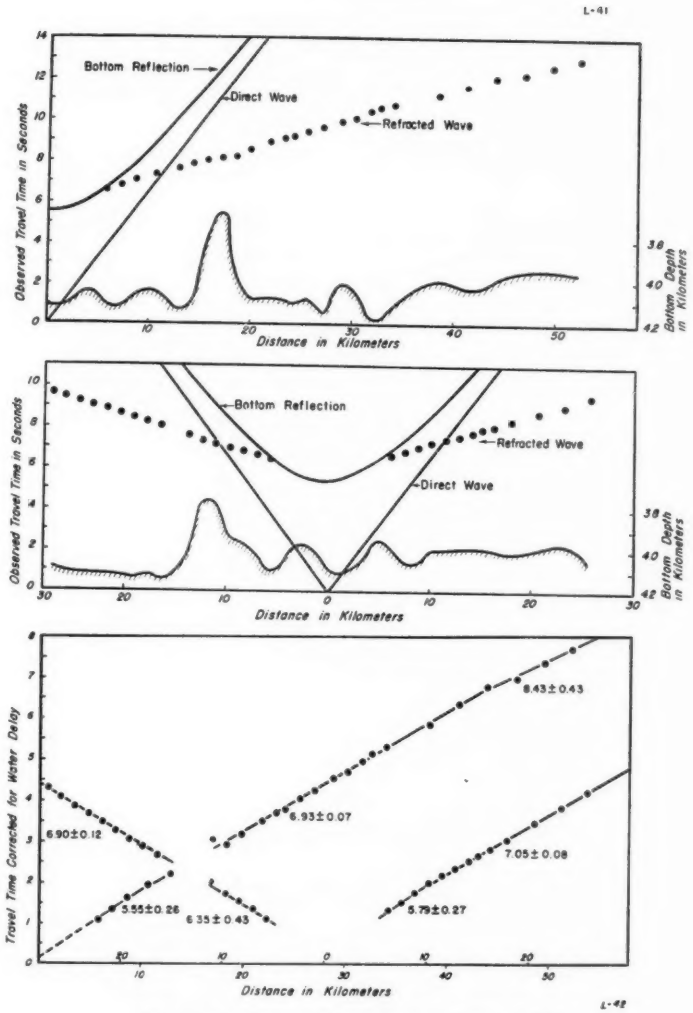

FIGURE 6.—TRAVEL-TIME PLOTS OF STATION M1

fracted sound waves become weak, and even if the shots are increased to the largest that can be conveniently thrown overside, the beginnings of many are hard to identify. Figure 5 illustrates the low-frequency traces of oscillograms of two shots of 80 pounds each at CAPRICORN station C12, recorded near the limit of detection of first arrivals.

TRAVEL-TIME DATA

In general, the records show an almost continuous succession of waves for many seconds after the first arrival. Some later arrivals can be traced from shot to shot. Those most consistently observed are multiply refracted waves arriving at intervals roughly equal to the intercept time. These waves have also been observed in the Atlantic Ocean (Ewing *et al.*, 1954). At some stations, at long range, refracted crustal waves are observed as strong second arrivals after a weak mantle wave. Less frequently, a mantle wave is observed following closely after the crust wave at ranges shorter than the crossover. At a few stations, waves appear to travel

as shear waves in the crust beneath the sediments (Ewing *et al.*, 1954).

In the present study, only first arrivals have been utilized. Examples of the observed travel-time data are shown in Figures 6 to 12. M1 and M7 are the stations for which the plans of operation are shown in Figures 2 and 3. The remainder are split profiles roughly similar to Figure 3. These examples illustrate the distances of the runs, the number of shots fired, and the variety of forms of the travel-time plots. They also show the roughness of bottom in many places and the variety of topographic forms, as well as the range of bottom depths.

Because the bottom depths vary from station to station as well as along the lines of the profiles, differences between travel-time plots in different areas are usually caused more by differences in sea depth and topography than by differences in crustal structure.

To facilitate the comparison of profiles taken in different areas, the first step in the data analysis is to correct each refracted-wave travel time for water delay at source and receiver. In the Figures, the travel times corrected for water delay are shown in the lower graphs. These corrected points give approximately the travel times that would have been observed if the shots and receivers had been placed on the bottom directly under their positions. Velocities are determined from the corrected plots.

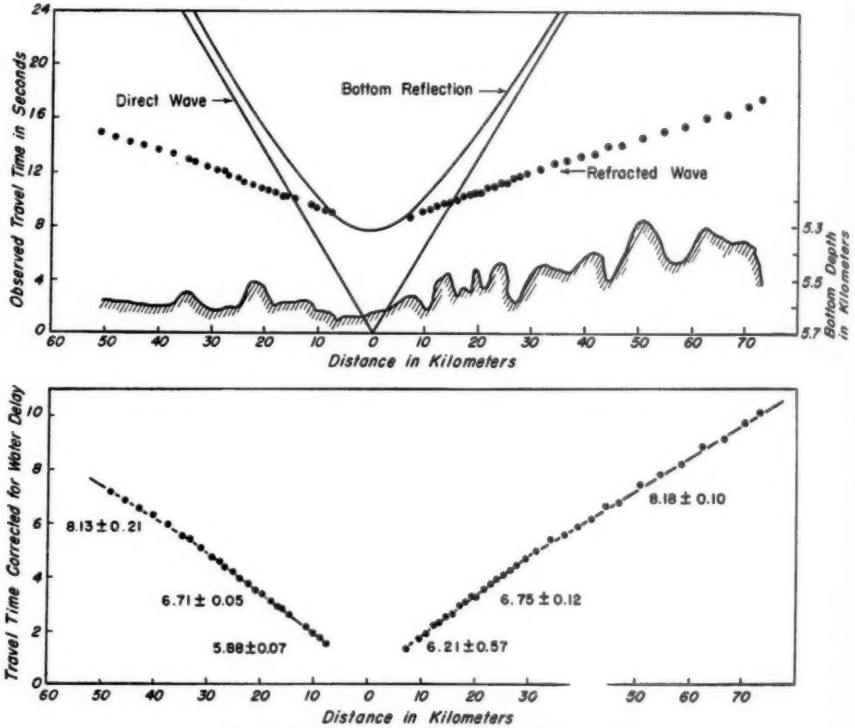

FIGURE 7.—TRAVEL-TIME PLOTS OF STA[illegible] M7

VELOCITIES

In the examples in Figures 6 to 12, most of the travel time data can be represented by three linear segments with velocities (in km/sec.) determined by least squares. The standard errors of the least-square determination are indicated.

Except in Figure 10, the maximum apparent velocities of all examples are more than 8 km/sec.; the examples in these Figures are representative of nearly all the deep-water profiles were recorded the average was taken of the two halves of the profile. At others, such as the reversed profile of Figure 2, three or four segments were included in some of the averages.

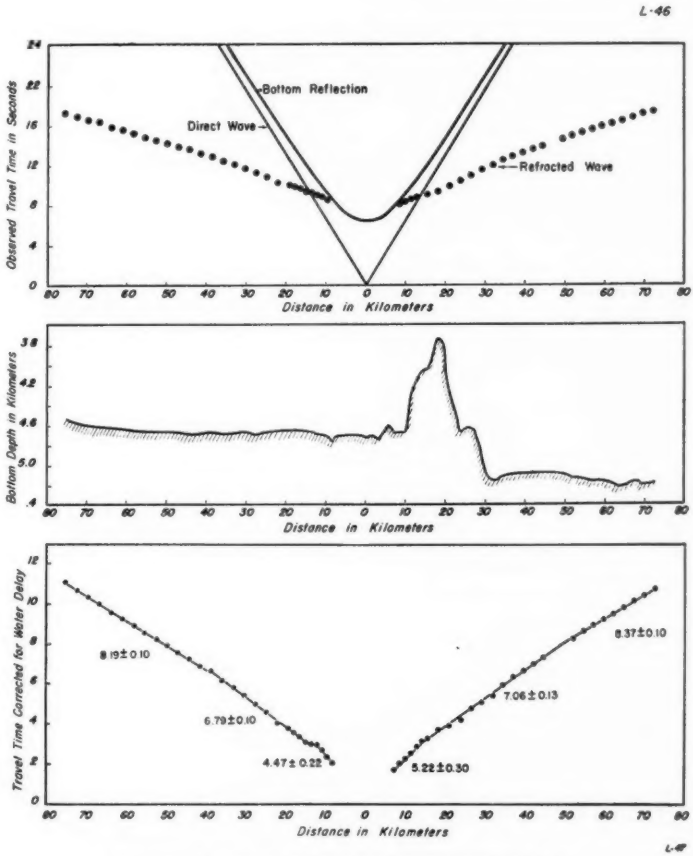

FIGURE 8.—TRAVEL-TIME PLOTS OF STATION M10

stations. In some, the segment indicating 8 km/sec. velocity was not observed, because the profile was short, the noise level was high, or the waves were too weak. In others, the short segment of lower velocity at the shortest shot distances was not observed.

At each station, the velocities were determined from the average of the slopes of corresponding segments of the travel-time distance plots. The result is the harmonic mean of the apparent velocities. At the stations where split

At nearly all stations, the short-range segment had a finite intercept at zero range, indicating that this segment, whose velocity is about 5 km/sec., represents a layer beneath the ocean floor covered with a layer of sediment. The velocity of the sediment was not determined from the refraction studies, because waves propagated through the sediment in deep water were not observed as first arrivals. Some unpublished estimates of velocities determined from reflection profiles give values of

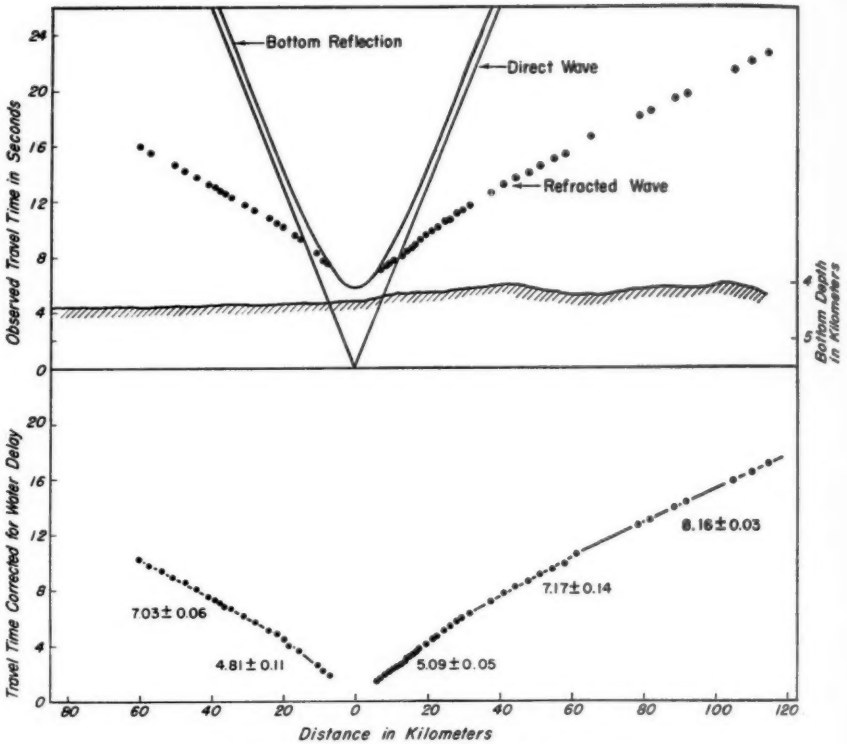

FIGURE 9.—TRAVEL-TIME PLOTS OF STATION C2

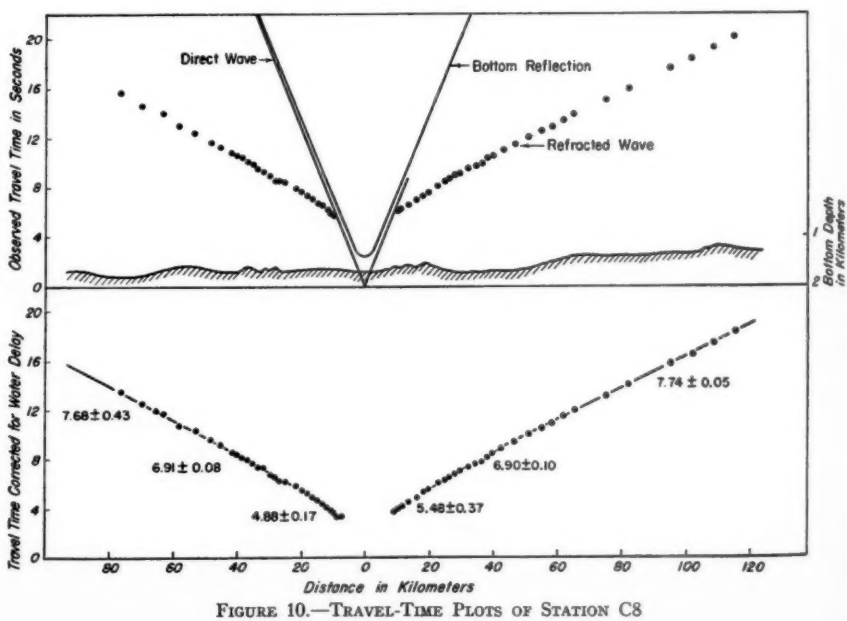

FIGURE 10.—TRAVEL-TIME PLOTS OF STATION C8

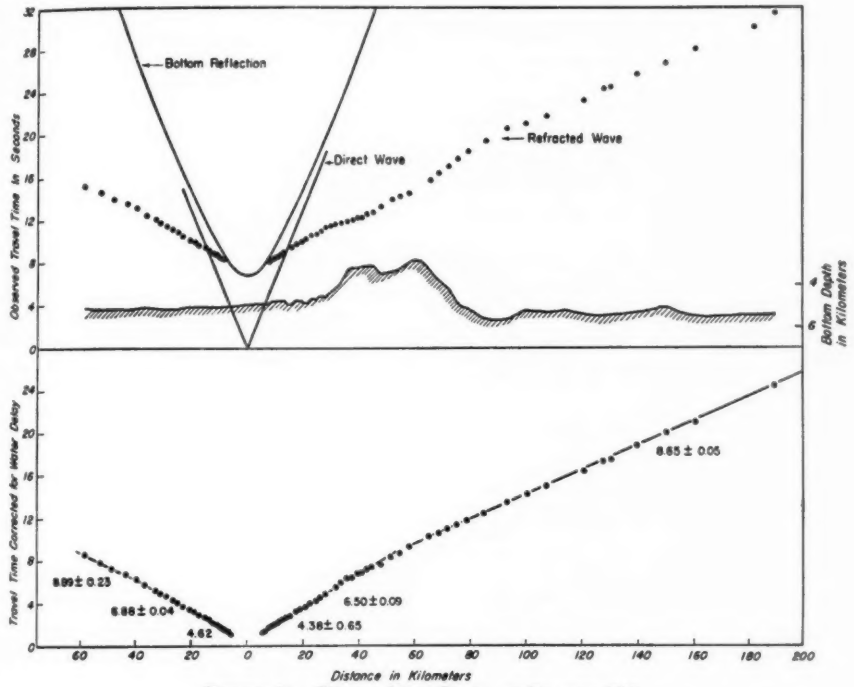

FIGURE 11.—TRAVEL-TIME PLOTS OF STATION C12

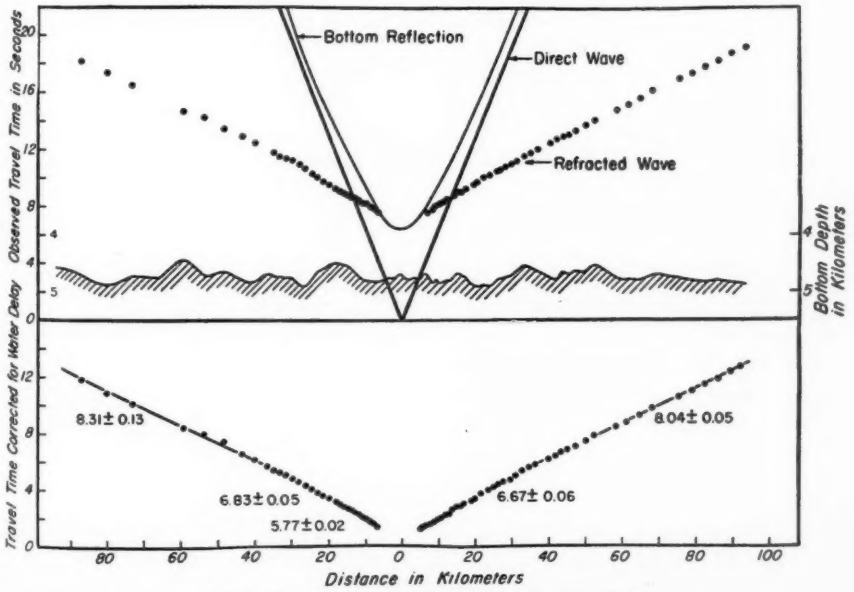

FIGURE 12.—TRAVEL-TIME PLOTS OF STATION C13

TABLE 3.—MID-PACIFIC VELOCITIES

Station	Second layer km/sec.	Third layer km/sec.	Fourth layer km/sec.
M1	5.88 ± 0.23	6.96 ± 0.08	8.41 ± 0.43
M2	5.97 ± 0.25	6.88 ± 0.09	8.05 ± 0.12
M3	.....	6.70 ± 0.10	.....
M4	5.76 ± 0.37	6.74 ± 0.10	.....
M5	6.32 ± 0.20	6.79 ± 0.05	.....
M6	.....	6.58 ± 0.15	8.24 ± 0.12
M7	6.04 ± 0.29	6.73 ± 0.07	8.15 ± 0.12
M9	4.26 ± 0.44	6.57 ± 0.20	7.92 ± 0.12
M10	4.81 ± 0.37	6.92 ± 0.13	8.28 ± 0.09
M11	4.86 ± 0.27	7.02 ± 0.15	.....
M12	4.92 ± 0.22	6.63 ± 0.06	.....
M13	6.24 ± 0.10	6.83 ± 0.06	.....
M14	4.39 ± 0.23	6.92 ± 0.10	8.42 ± 0.12
M15	5.16 ± 0.16	6.56 ± 0.15	8.28 ± 0.21
Mean	5.38	6.77	8.22
Standard deviation	0.73	0.15	0.17

TABLE 4.—CAPRICORN VELOCITIES

Station	Second layer km/sec.	Third layer km/sec.	Fourth layer km/sec.
C1	4.15 ± 0.06 5.59 ± 0.08†	6.90 ± 0.10	8.09 ± 0.23
C2	4.98 ± 0.11	7.10 ± 0.08	8.16 ± 0.03
C3	5.73 ± 0.09	6.72 ± 0.40	8.14 ± 0.12
C5	4.55 ± 0.76*	6.43 ± 0.30	8.14 ± 0.06
C6	5.37 ± 0.33	6.55 ± 0.32	8.51 ± 0.43*
C7	5.00 ± 0.57	7.04 ± 0.04	8.42 ± 0.29
C8	5.17 ± 0.29	6.92 ± 0.08	7.71 ± 0.21*
C9	3.93*	6.42 ± 0.06	8.25 ± 0.12
C10, 11	5.31 ± 0.35	6.69 ± 0.33	8.29 ± 0.10
C12	4.49 ± 0.65*	6.68 ± 0.19	8.77 ± 0.12
C13	5.77	6.75 ± 0.08	8.17 ± 0.13
C14	4.64 ± 0.28*	6.45 ± 0.13	8.21 ± 0.11
C15	4.48 ± 0.10	6.81 ± 0.26	8.43 ± 0.28
C16	5.51 ± 0.36	6.69 ± 0.20	8.34 ± 0.09
C18	5.04 ± 0.24	6.91 ± 0.06	8.14 ± 0.20
C19	5.22 ± 0.26	6.69 ± 0.10	8.00 ± 0.05
C20	4.35 ± 0.12*	6.48 ± 0.17	8.12 ± 0.07
C21	4.82 ± 0.27	6.88 ± 0.07	7.66 ± 0.04*
C22	5.11 ± 0.54	7.03 ± 0.09	7.36 ± 0.22*
C23	6.02 ± 0.15	6.90 ± 0.14	8.30 ± 0.28
C24	4.92 ± 0.86	6.84 ± 0.16	8.21 ± 0.10
C25	5.78 ± 0.25	6.90 ± 0.03	8.16 ± 0.06
C26	4.52 ± 0.21	6.78 ± 0.08	8.46 ± 0.20
Mean	5.09	6.76	8.25
Standard deviation	0.52	0.20	0.18

* Omitted from averages and standard deviations.

† At Eniwetok two layers were observed whose velocities were comparable to the second layer.

about 2 to 2½ km/sec. for the average velocity to the base of the sediment. The present average of these determinations is 2.15 km/sec., a value assumed for all the stations in this paper. This value will be compared with the values of 1.5 to 2.3 km/sec. observed in the western Atlantic Ocean (Ewing, Sutton, and Officer, 1954; Katz and Ewing, 1956), and the value of 2.1 km/sec. obtained in the eastern Atlantic (Hill and Laughton, 1954) and in the Pacific (J. C. Swallow, 1954, Cambridge Univ., Ph.D. Thesis). It is unlikely that the assumed value of 2.15 km/sec. will differ from the average vertical velocity of the unconsolidated sediment by more than 20 per cent. The resultant error of sediment thickness is less than 100 m in most cases.

The mean velocities and estimated standard errors for each station are tabulated in Tables 3 and 4. The standard errors were estimated from the differences of the slopes entering into the mean-velocity determination and are generally larger than the standard errors calculated from the residuals of the least-square determinations of slope. In estimating the standard errors of the velocities, it was assumed that the individual determinations making up the station average were statistically independent. A systematic trend of structure, such as a linear thickening or constant slope of interfaces extending over the area, would cause the estimated error to be too large.

For all layers, the range of variation of velocities is greater than the estimated standard errors of measurement. In the third and fourth layers, this effect is large enough to be statistically significant but not large enough to prove that the effect is real and not due to random errors of measurement of velocity. In the second layer, however, the variation is so large that there is little doubt that it is real, in spite of the large error in velocity measurement.

The variation in the second layer is particularly evident in the MID-PACIFIC data where there are systematic regional effects. Stations M1 to M7 east of Hawaii have a higher velocity of the second layer than those in the region of the Hawaiian Islands, the Mid-Pacific Mountains (Dietz *et al.*, 1954), and the Marshall Islands to the west. The single exception to this separation is station M13, which lies between the Mid-Pacific Mountains and the Marshall Islands and appears to resemble the eastern Pacific in velocity structure.

There is no simple geographical division of the CAPRICORN velocities for the second layer.

TABLE 5.—MID-PACIFIC LAYER THICKESSES

Station	First layer km	Second layer km	Third layer km	Total thickness km
M1	0.26	0.93	6.24	7.43
M2	0.17	1.42	4.31	5.90
M3*	0.31	0.70	....	....
M4	0.45	0.35	....	....
M5	0.57	1.16	....	....
M6*	0.20	0.72	4.42	5.35
M7	0.32	0.81	4.14	5.27
M9	0.24	2.27	4.70	7.22
M10	0.34	2.21	5.66	8.22
M11	0.42	2.18	....	....
M12	0.40	2.59	....	....
M13	0.62	1.57	....	....
M14	0.57	2.60	3.14	6.31
M15	1.07	1.90	5.69	8.66

* Velocity of 5.99 km/sec. assumed for second layer

However, the two highest values of second-layer velocity obtained on the CAPRICORN expedition are at stations C23 and C25, which are not far from the region of high velocity of the MID-PACIFIC expedition.

LAYER THICKNESSES

Calculation of the velocity-depth structure from the observed travel times was based on a simplified model of layers of constant velocity as determined from the travel-time plots. Methods have been summarized in several geophysical textbooks (Nettleton, 1940; Dix, 1952; Dobrin, 1952). This model represents a simplification of the actual situation, where velocities probably vary continuously with depth and possibly with horizontal distance, but it is a rough approximation and provides a basis for comparison of results.

No attempt was made to work out horizontal changes in structure within the areas of observation at each station. The purpose of the present study is to describe the Pacific Basin as an entity, and only average layer thicknesses were determined.

as shear waves in the crust beneath the sediments (Ewing *et al.*, 1954).

In the present study, only first arrivals have been utilized. Examples of the observed travel-time data are shown in Figures 6 to 12. M1 and M7 are the stations for which the plans of operation are shown in Figures 2 and 3. The remainder are split profiles roughly similar to Figure 3. These examples illustrate the distances of the runs, the number of shots fired, and the variety of forms of the travel-time plots. They also show the roughness of bottom in many places and the variety of topographic forms, as well as the range of bottom depths.

Because the bottom depths vary from station to station as well as along the lines of the profiles, differences between travel-time plots in different areas are usually caused more by differences in sea depth and topography than by differences in crustal structure.

To facilitate the comparison of profiles taken in different areas, the first step in the data analysis is to correct each refracted-wave travel time for water delay at source and receiver. In the Figures, the travel times corrected for water delay are shown in the lower graphs. These corrected points give approximately the travel times that would have been observed if the shots and receivers had been placed on the bottom directly under their positions. Velocities are determined from the corrected plots.

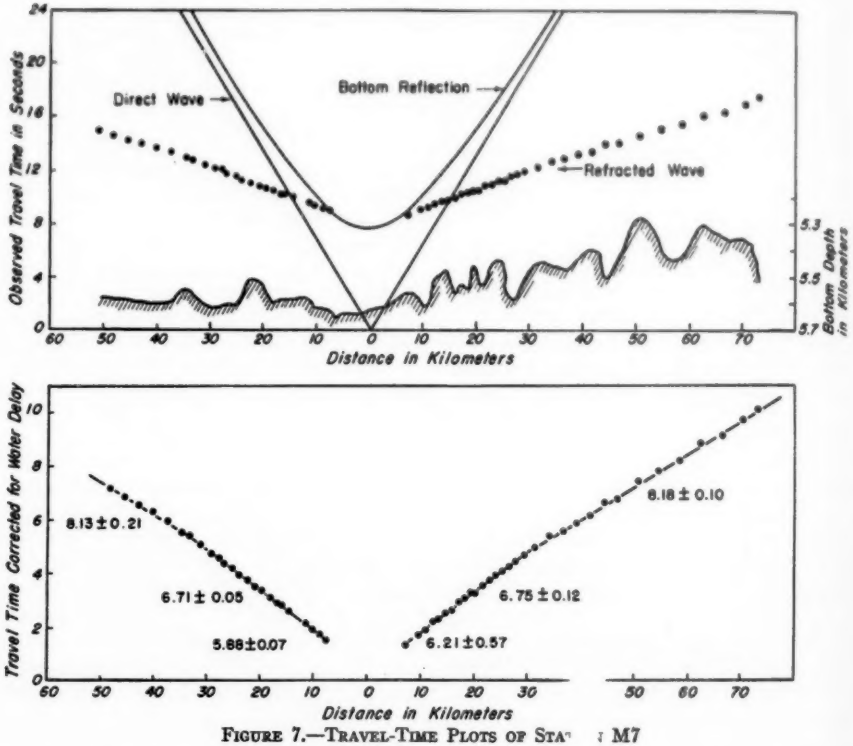

FIGURE 7.—TRAVEL-TIME PLOTS OF STA[illegible] M7

VELOCITIES

In the examples in Figures 6 to 12, most of the travel time data can be represented by three linear segments with velocities (in km/sec.) determined by least squares. The standard errors of the least-square determination are indicated.

Except in Figure 10, the maximum apparent velocities of all examples are more than 8 km/sec.; the examples in these Figures are representative of nearly all the deep-water profiles were recorded the average was taken of the two halves of the profile. At others, such as the reversed profile of Figure 2, three or four segments were included in some of the averages.

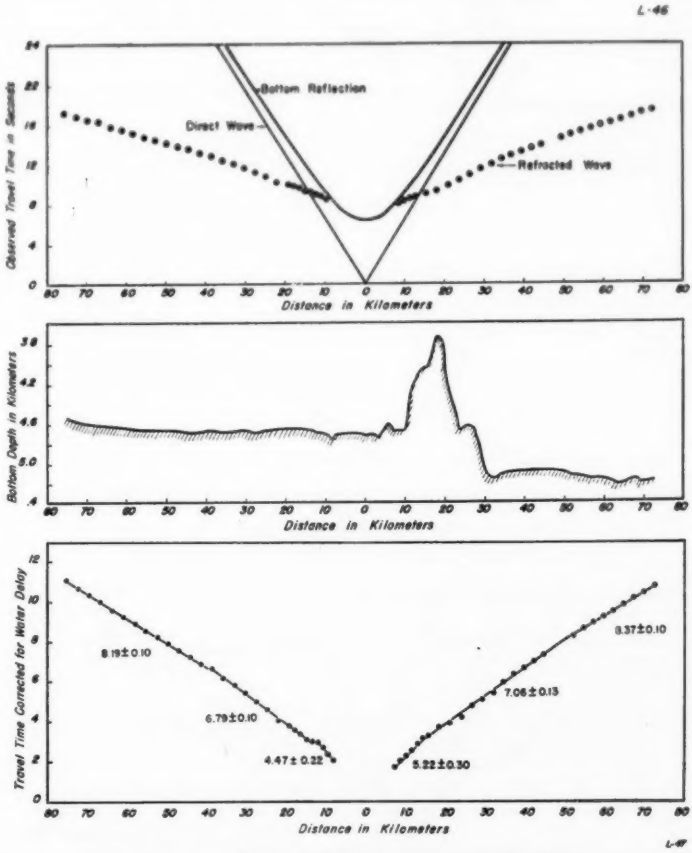

FIGURE 8.—TRAVEL-TIME PLOTS OF STATION M10

stations. In some, the segment indicating 8 km/sec. velocity was not observed, because the profile was short, the noise level was high, or the waves were too weak. In others, the short segment of lower velocity at the shortest shot distances was not observed.

At each station, the velocities were determined from the average of the slopes of corresponding segments of the travel-time distance plots. The result is the harmonic mean of the apparent velocities. At the stations where split

At nearly all stations, the short-range segment had a finite intercept at zero range, indicating that this segment, whose velocity is about 5 km/sec., represents a layer beneath the ocean floor covered with a layer of sediment. The velocity of the sediment was not determined from the refraction studies, because waves propagated through the sediment in deep water were not observed as first arrivals. Some unpublished estimates of velocities determined from reflection profiles give values of

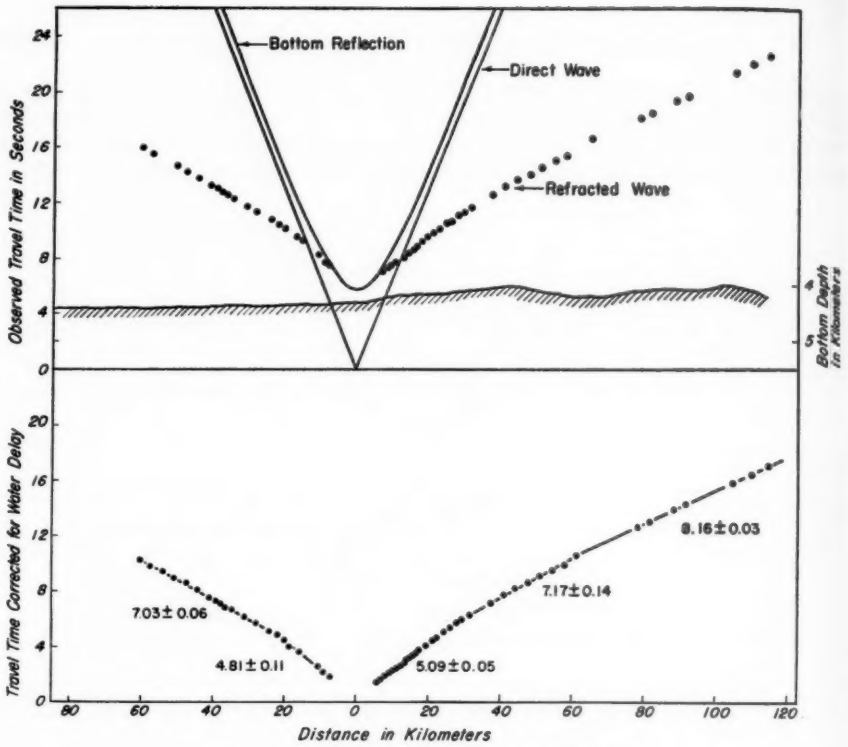

FIGURE 9.—TRAVEL-TIME PLOTS OF STATION C2

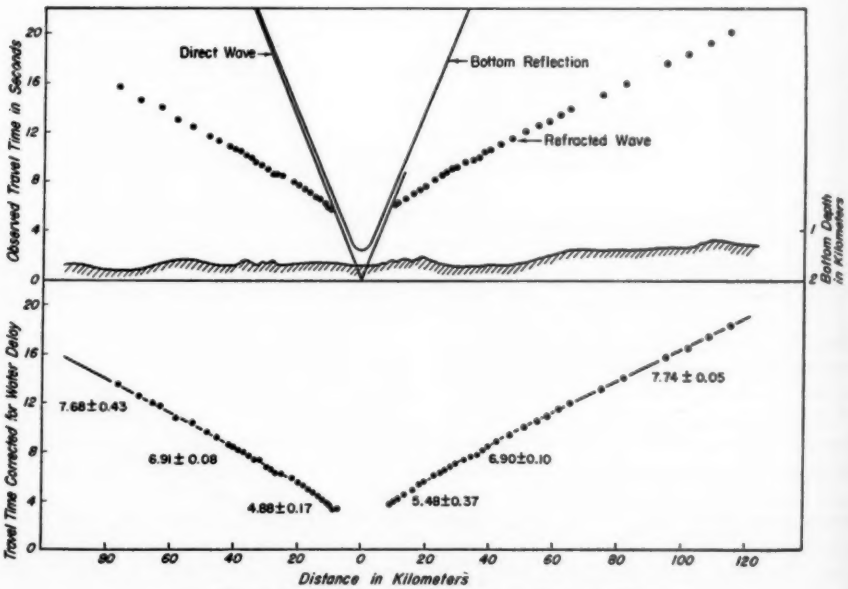

FIGURE 10.—TRAVEL-TIME PLOTS OF STATION C8

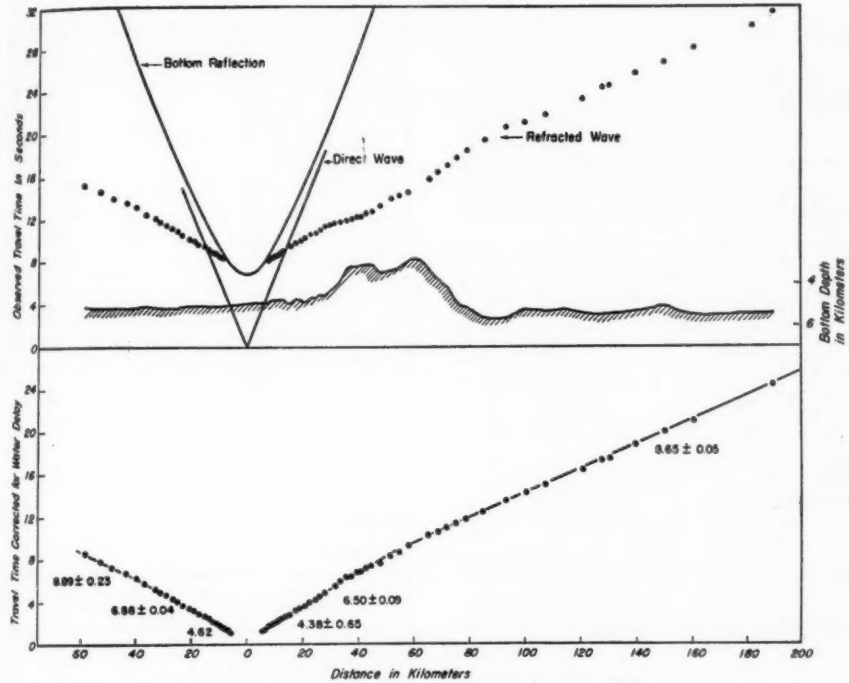

FIGURE 11.—TRAVEL-TIME PLOTS OF STATION C12

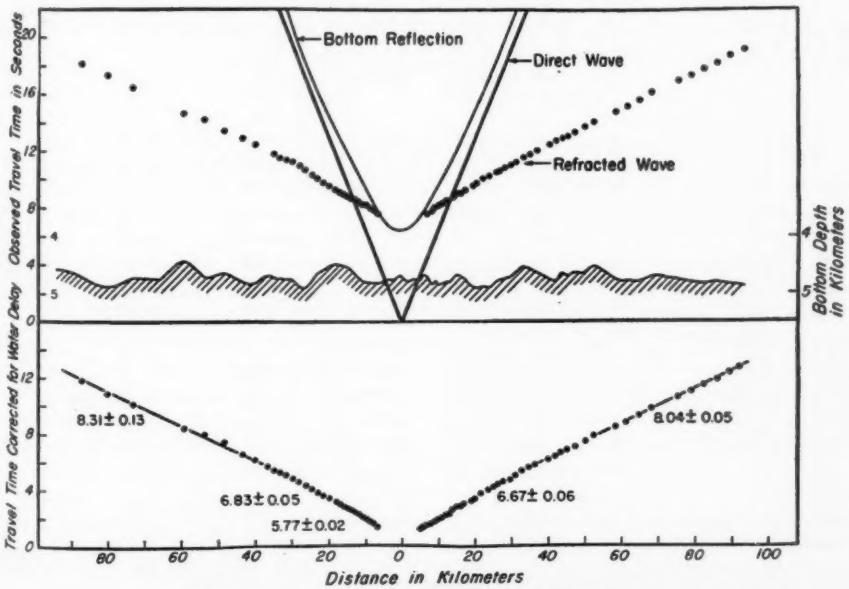

FIGURE 12.—TRAVEL-TIME PLOTS OF STATION C13

TABLE 3.—MID-PACIFIC VELOCITIES

Station	Second layer km/sec.	Third layer km/sec.	Fourth layer km/sec.
M1	5.88 ± 0.23	6.96 ± 0.08	8.41 ± 0.43
M2	5.97 ± 0.25	6.88 ± 0.09	8.05 ± 0.12
M3	.....	6.70 ± 0.10	.....
M4	5.76 ± 0.37	6.74 ± 0.10	.....
M5	6.32 ± 0.20	6.79 ± 0.05	.....
M6	.....	6.58 ± 0.15	8.24 ± 0.12
M7	6.04 ± 0.29	6.73 ± 0.07	8.15 ± 0.12
M9	4.26 ± 0.44	6.57 ± 0.20	7.92 ± 0.12
M10	4.81 ± 0.37	6.92 ± 0.13	8.28 ± 0.09
M11	4.86 ± 0.27	7.02 ± 0.15	.....
M12	4.92 ± 0.22	6.63 ± 0.06	.....
M13	6.24 ± 0.10	6.83 ± 0.06	.....
M14	4.39 ± 0.23	6.92 ± 0.10	8.42 ± 0.12
M15	5.16 ± 0.16	6.56 ± 0.15	8.28 ± 0.21
Mean	5.38	6.77	8.22
Standard deviation	0.73	0.15	0.17

TABLE 4.—CAPRICORN VELOCITIES

Station	Second layer km/sec.	Third layer km/sec.	Fourth layer km/sec.
C1	4.15 ± 0.06 5.59 ± 0.08†	6.90 ± 0.10	8.09 ± 0.23
C2	4.98 ± 0.11	7.10 ± 0.08	8.16 ± 0.03
C3	5.73 ± 0.09	6.72 ± 0.40	8.14 ± 0.12
C5	4.55 ± 0.76*	6.43 ± 0.30	8.14 ± 0.06
C6	5.37 ± 0.33	6.55 ± 0.32	8.51 ± 0.43*
C7	5.00 ± 0.57	7.04 ± 0.04	8.42 ± 0.29
C8	5.17 ± 0.29	6.92 ± 0.08	7.71 ± 0.21*
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C13	5.77	6.75 ± 0.08	8.17 ± 0.13
C14	4.64 ± 0.28*	6.45 ± 0.13	8.21 ± 0.11
C15	4.48 ± 0.10	6.81 ± 0.26	8.43 ± 0.28
C16	5.51 ± 0.36	6.69 ± 0.20	8.34 ± 0.09
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C19	5.22 ± 0.26	6.69 ± 0.10	8.00 ± 0.05
C20	4.35 ± 0.12*	6.48 ± 0.17	8.12 ± 0.07
C21	4.82 ± 0.27	6.88 ± 0.07	7.66 ± 0.04*
C22	5.11 ± 0.54	7.03 ± 0.09	7.36 ± 0.22*
C23	6.02 ± 0.15	6.90 ± 0.14	8.30 ± 0.28
C24	4.92 ± 0.86	6.84 ± 0.16	8.21 ± 0.10
C25	5.78 ± 0.25	6.90 ± 0.03	8.16 ± 0.06
C26	4.52 ± 0.21	6.78 ± 0.08	8.46 ± 0.20
Mean	5.09	6.76	8.25
Standard deviation	0.52	0.20	0.18

* Omitted from averages and standard deviations.

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M4	0.45	0.35	....	....
M5	0.57	1.16	....	....
M6*	0.20	0.72	4.42	5.35
M7	0.32	0.81	4.14	5.27
M9	0.24	2.27	4.70	7.22
M10	0.34	2.21	5.66	8.22
M11	0.42	2.18	....	....
M12	0.40	2.59	....	....
M13	0.62	1.57	....	....
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M15	1.07	1.90	5.69	8.66

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However, the two highest values of second-layer velocity obtained on the CAPRICORN expedition are at stations C23 and C25, which are not far from the region of high velocity of the MID-PACIFIC expedition.

LAYER THICKNESSES

Calculation of the velocity-depth structure from the observed travel times was based on a simplified model of layers of constant velocity as determined from the travel-time plots. Methods have been summarized in several geophysical textbooks (Nettleton, 1940; Dix, 1952; Dobrin, 1952). This model represents a simplification of the actual situation, where velocities probably vary continuously with depth and possibly with horizontal distance, but it is a rough approximation and provides a basis for comparison of results.

No attempt was made to work out horizontal changes in structure within the areas of observation at each station. The purpose of the present study is to describe the Pacific Basin as an entity, and only average layer thicknesses were determined.

The results of the layer-thickness calculations are presented in Tables 5 and 6. All thicknesses of the first layer, the unconsolidated sediment, were calculated with an assumed velocity of 2.15 km/sec. In the following cases where the velocity data were poor or missing, or for special reasons, such as rough topography, records were probably unreliable, average velocities from other stations were used to calculate layer thicknesses. In the MID-PACIFIC results, a velocity of 5.99 km/sec. was assumed for the second layer at stations M3 and M6. This velocity is the average for this layer for the other stations in the eastern portion of this cruise, stations M1, M2, M4, M5, and M7. At stations C5, C9, C12, C14, and C20, a velocity of 5.09 km/sec. was assumed for the second layer. This velocity is the average for this layer at the other CAPRICORN stations. Otherwise, the velocities used in the layer calculations are those tabulated in Tables 3 and 4.

TABLE 6.—CAPRICORN LAYER THICKNESSES

Station	First layer km	Second layer km	Third layer km	Total thickness km
C1*	0.95	{2.41 / 3.43}	5.76	12.55
C2	0.20	5.40	7.41	13.01
C3	0.31	2.10	4.23	6.64
C5†	0.42	0.95	4.28	5.64
C6	0.90	2.47	9.16	12.53
C7	1.14	2.02	7.41	10.57
C8	2.12	2.80	....	.....
C9†	0.41	0.45	5.27	6.14
C10, 11†	NIL	2.90	8.26	11.16
C12	0.16	1.51	9.58	11.25
C13	0.35	0.86	4.90	6.11
C14†	0.07	1.16	4.62	5.86
C15	0.24	1.54	5.37	7.15
C16	0.24	1.31	5.90	7.46
C18	0.20	1.59	4.57	6.35
C19	0.22	0.81	4.60	5.64
C20†	0.27	0.73	4.24	5.24
C21	0.28	1.06	....	.....
C22	0.22	1.16	....	.....
C23	0.34	1.20	3.31	4.85
C24	0.38	1.18	4.03	5.59
C25	0.53	0.66	4.19	5.38
C26	0.03	1.26	5.12	6.41

* At Eniwetok the two layers were included in the velocity range of the second layer.

† Velocity of 5.09 km/sec. assumed for second layer

At stations C8, C21, and C22 the maximum velocities of 7.71, 7.66, and 7.36 km/sec. were not considered large enough to prove that penetration to the base of the crust had been achieved. Consequently, estimates of third-layer thickness are not given for these stations.

At the two stations, M3 and M6, where the short-range refraction data were too poor to establish the existence of the second layer, intercepts were calculated by assuming that the first arrivals at the shortest range had travelled through the second layer at the assumed velocity of 5.99 km/sec. In view of the position of M3 and M6 within the relatively homogeneous group M1 to M7, this procedure is more realistic than assuming that the second layer does not exist.

NATURE OF THE LAYERS

FIRST LAYER: The only layer which can be positively identified everywhere by sampling and observation is the upper layer, the blanket of unconsolidated sediment which covers most of the sea floor. The value of 2.15 km/sec. estimated for its average velocity indicates a substantial increase with depth in the sediment, as samples from the sea floor have shown values differing little from that of water, 1.5 km/sec. (Shumway, 1956; Laughton, 1954; Officer, 1955).

SECOND LAYER: The large range of velocities of the second layer indicates that it may consist of a variety of materials. At Eniwetok (station C1) samples of volcanic rock were taken on the atoll with a core drill at a depth of about 1300 m (Ladd *et al.*, 1953). Its velocity as measured by refraction (Raitt, in press) was near the lower end of the range of the second-layer values, about 4 km/sec.

The higher values of the second-layer velocities, most consistently observed at the MID-PACIFIC stations east of Hawaii, are in the 6 km/sec. range, comparable to sialic or granitic velocities characteristic of continental areas.

From these observations it could be concluded that certain areas, such as the region between Hawaii and the North American continent to the east, have a thin layer of sial about 1 km thick lying between the unconsolidated sedi-

ment and the principal crustal layer (the third layer). In other regions, such as the Mid-Pacific Mountains and the Marshall Islands, the layer between the sediments and the main crust could be largely volcanic and about 2 km thick.

These deductions are speculative. Many other types of rocks, such as limestones, schists, chert, and other forms of consolidated sediment could have the velocities observed in the second layer.

THIRD LAYER: The third layer is the principal one of the Pacific oceanic crust. It forms the most conspicuous segment within the inner 60 km of the travel-time plots and it is observed at all the Pacific stations west of the continental slope. If a similar layer has widespread occurrence beneath the continents, it is buried under a thick layer of material of lower velocity and could be concealed by earlier arrivals through the upper layers or through the mantle.

The layer is not known to outcrop anywhere in the Pacific and it has not been directly identified. Its velocity is intermediate between that of granite and that of dunite, and it is probably an intermediate type, more basic than granite, less basic than dunite. It is often called the simatic or "basaltic" layer. In crystalline structure, it would probably be similar to gabbro, as it would be unlikely to have the fine-grained structure of basalts.

The variation of its velocity, if real, indicates that it is not everywhere uniform. However, there is no systematic difference between the average values obtained on the MID-PACIFIC and CAPRICORN expeditions. Hence, the variations are localized, and over large areas the velocity seems to be uniform.

FOURTH LAYER: At most stations, the velocity of the outermost segments of the travel-time plots reached a value of about 8 km/sec. or more, believed to be characteristic of the upper mantle immediately below the Mohorovičić discontinuity. At stations C8, C21, and C22, fourth-layer velocities were 7.71, 7.66, and 7.36 km/sec. respectively. These were believed to be too low to be characteristic of the base of the crust and were not used in determining the fourth-layer average velocities or the thicknesses of the third layer. Of the velocities considered indicative of paths in the mantle, the lowest was 7.92 km/sec. at M9.

Excluding the three anomalous values, the averages of the fourth-layer velocities were 8.22 km/sec. for the MID-PACIFIC stations and 8.25 km/sec. for the CAPRICORN stations. These values are close to the upper-mantle velocities observed in continental areas from blasts and rock bursts (Gutenberg, 1955). It is therefore reasonable to assume by analogy with continental results that the fourth layer, except for the anomalous stations C8, C21, and C22, underlies the oceanic crust. The variability of its velocity, if real, indicates that it is not homogeneous. However, as in the third layer, there is no significant difference in the averages of the MID-PACIFIC and CAPRICORN velocities, showing that over large areas the mantle is uniform.

CRUSTAL THICKNESS

The crust consists of the material above the mantle. Its thickness is obtained by adding the thicknesses of the first three layers. These thicknesses are tabulated in the last columns of Tables 5 and 6.

Only stations at which a velocity of at least 7.9 km/sec. was reached were used in this crustal-thickness determination. The three anomalous stations, C8, C21, and C22 were not used for this determination because they are probably too low to represent the base of the crust, and the crustal thickness was not estimated for these stations. All three are in anomalous positions with respect to the true Pacific Basin. C8 is in the Tonga Islands, and C21 and C22 are on the Albatross Plateau. These elevated regions show an abnormally low velocity beneath the third layer rather than an increase in depth of the fourth layer. This indicates that isostatic compensation is not accomplished in these areas by a simple increase in the thickness of the first three layers. The lower velocity at stations C21 and C22 may be associated with an effect observed by Oliver, Ewing, and Press (1955) who found that surface waves crossing this region had lower velocities than generally observed in the Pacific Basin.

In Figure 13, all the crustal thicknesses are plotted as a function of the elevation of the sea floor with respect to sea level. A few representative values of continental crustal thicknesses

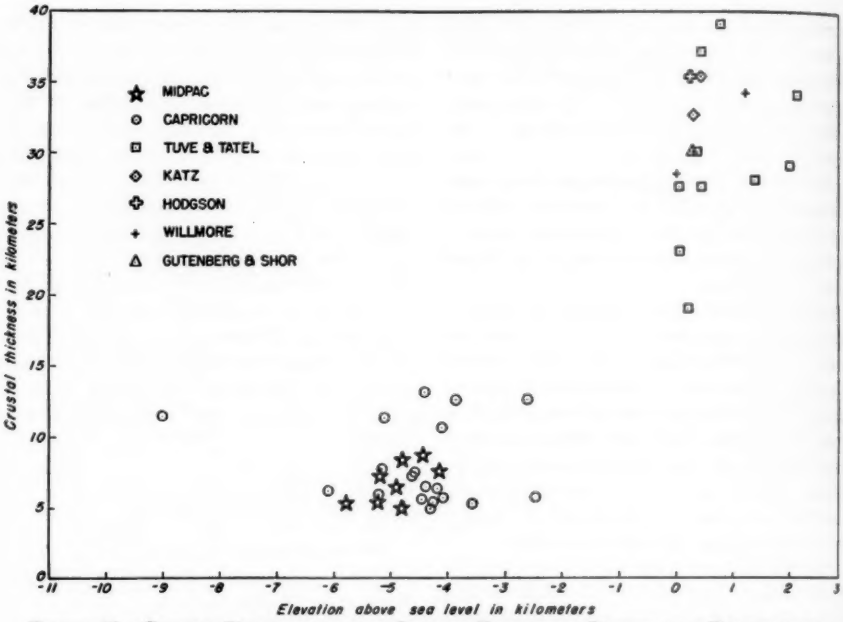

FIGURE 13.—CRUSTAL THICKNESS OF THE CENTRAL EQUATORIAL PACIFIC AS A FUNCTION OF SEA-FLOOR ELEVATION

Some continental determinations are shown for comparison.

determined by blast and rock-burst observations (Tatel and Tuve, 1955; Katz, 1953; Hodgson, 1953; Willmore, 1949; Willmore *et al* 1952; Gutenberg, 1952; Shor, 1955) are also plotted.

Although there is a systematic difference between oceanic and continental crust, there is no systematic dependence on elevation within the continental region or within the Pacific oceanic region, an observation which has been noted for the continental areas by Tatel and Tuve (1955).

The oceanic measurements cluster into two groups, with thicknesses greater or less than 10 km. The first group consists of stations C1, C2, C6, C7, C10, C11, and C12. All these stations are near the western border of the region studied and are probably anomalous with respect to the Pacific Basin proper. The remaining 22 stations are closely grouped, and their mean thickness is 6.31 km, with a standard deviation of 1.01 km.

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CRUSTAL STRUCTURE IN NORTHERN AND MIDDLE CALIFORNIA FROM GRAVITY-PENDULUM DATA

BY CHUJI TSUBOI

ABSTRACT

The variation in the thickness of the earth's crust along the composite east-west profile in northern and middle California has been investigated on the basis of pendulum gravity data published by J. A. Duerksen. The earth's crust is about 24 km thick beneath the California coast line, and the thickness increases inland until it is 50 km at a point 350 km from the coast line. It has been deduced also that the deposits in the Central Valley increase in density rapidly with depth so that at depths of a few kilometers there is no appreciable density contrast with the basement rocks.

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INTRODUCTION

A map of the United States on which are drawn lines of equal Bouguer gravity anomalies based on values published by J. A. Duerksen (1949) shows that to the west of the Sierra Nevada and in a span between the parallels 39° N. and 35° N. the lines are approximately parallel to each other and also to the Pacific coast (Fig. 1). The gravity anomalies in this area may therefore be regarded with good approximation as one dimensional in distribution so that the shape of the bottom surface of the earth's crust[1] can be deduced by relatively simple mathematics. It is assumed that the variation in gravity anomalies is due to the undulation of the Mohorovicic-discontinuity surface bounding the lighter crustal material above it and the denser subcrustal material below it. The calculations in this paper are based on the composite profile of the anomalies along the direction normal to the coast line (Fig. 2).

[1] Earth's crust as used here means that portion of the earth that lies above the Mohorovičič discontinuity.

ACKNOWLEDGMENTS

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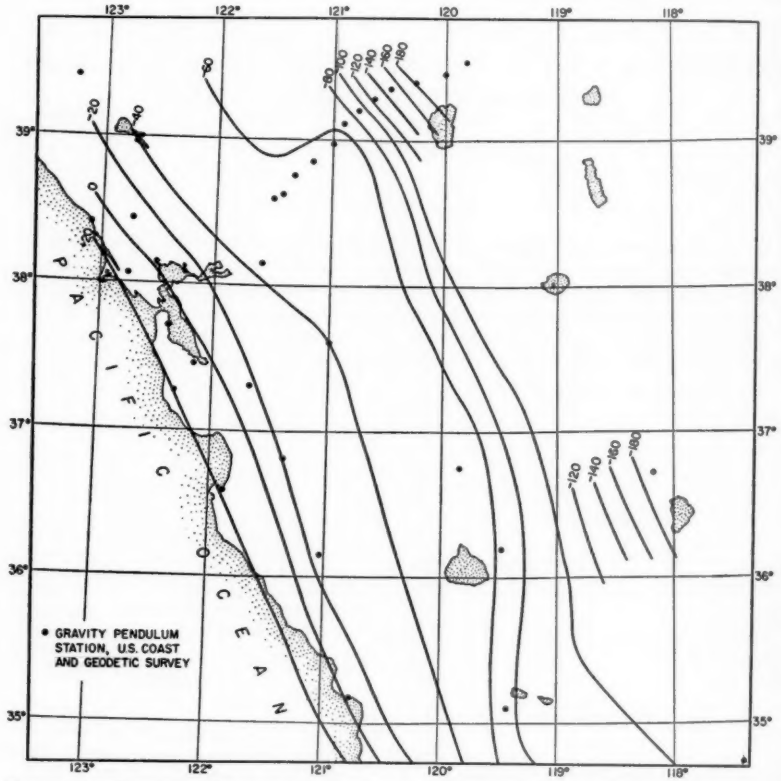

FIGURE 1.—BOUGUER GRAVITY ANOMALIES IN NORTHERN AND MIDDLE CALIFORNIA

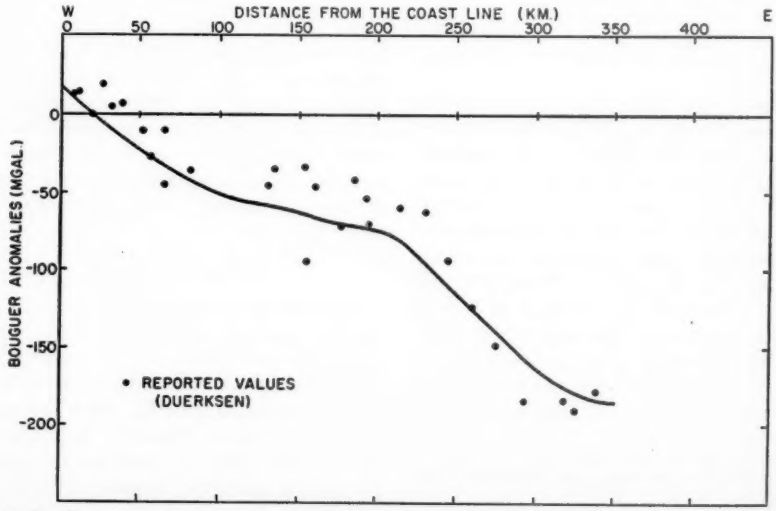

FIGURE 2.—COMPOSITE PROFILE OF THE BOUGUER ANOMALY DISTRIBUTION IN THE DIRECTION NORMAL TO THE COAST LINE

the course of this study. Dr. Frank Press was kind enough to read carefully through the manuscript.

Method

The method of analysis used in this study, described by Tomoda and Aki (1955), is much simpler and easier to use than the Fourier series method (Tsuboi and Fuchida, 1938).

The function $(\sin x)/x$ takes unit value at $x = 0$ and becomes zero at $x = n\pi$, where n can be any interger other than zero. This function can be written

$$\frac{\sin x}{x} = \int_0^1 \cos mx \, dm. \tag{1}$$

The upper limit of integration with respect to m is 1 means that no harmonic components higher than order $m = 1$ are contained in this function. In this sense, the curve is smooth between any two consecutive grid points, which are π apart.

It is known from potential theory (Tsuboi and Fuchida, 1938) that if

$$\Delta g(x) = B_m \begin{matrix}\cos \\ \sin\end{matrix} mx \tag{2}$$

represents the gravity anomaly distribution along the earth's surface, the distribution of mass $M(x)$ condensed on a single plane at depth d which is needed to produce this gravity distribution is given by

$$M(x) = \frac{1}{2\pi G} B_m \begin{matrix}\cos \\ \sin\end{matrix} mxe^{md}, \tag{3}$$

where G is the Newtonian constant of gravitation. Applying this relation, the distribution of mass which is needed to produce the gravity anomaly

$$\Delta g(x) = b \frac{\sin x}{x} \tag{4}$$

is given by

$$M(x) = \frac{b}{2\pi G} \int_0^1 \cos mxe^{md} \, dm. \tag{5}$$

This can be integrated into

$$M(x) = \frac{b}{2\pi G} \frac{1}{x^2 + d^2} \cdot [(d \cos x + x \sin x)e^d - d]. \tag{6}$$

At $x = n\pi$, $M(x)$ takes the value

$$M(n\pi) = \frac{b}{2\pi G} \frac{d}{(n\pi)^2 + d^2} \cdot (\pm e^d - 1). \qquad \begin{matrix}+: n \text{ even} \\ -: n \text{ odd}\end{matrix} \tag{7}$$

In these formulae, d is expressed in radians when the distance between two consecutive grid points is taken as π. If this distance is a in the actual scale, then

$$d = \pi D/a,$$

where D is the actual depth of the plane on which the mass is assumed to be condensed. Thus the expression for $M(na)$ becomes

$$M(na) = \frac{b}{2\pi^2 G} \frac{1}{n^2 + (D/a)^2} (\pm e^{\pi D/a} - 1). \tag{8}$$

If the depth of the plane and the horizontal distance between two consecutive grid points are equal, that is if $D/a = 1$,

$$M(na) = \frac{b}{2\pi^2 G} \frac{1}{n^2 + 1} (\pm e^{\pi} - 1) = b\phi(n). \tag{9}$$

Some of the values of $\phi(n)$ are given in Table 1.

If the values of gravity anomalies observed at a series of equidistant grid points along the earth's surface are b_{-5}, b_{-4}, b_{-3}, b_{-2}, b_{-1}, b_0, b_1, b_2, b_3, b_4, b_5, the total mass $m(na)$ (per unit length) beneath the grid point $x = na$ is given by

Table 1.—Values of the Function $\phi(n)$ for $D = a$

n	$\phi(n)$ in 10^7	n	$\phi(n)$ in 10^7
0	1.6819	±11	−0.0150
±1	−0.9167	±12	0.0116
±2	0.3363	±13	−0.0108
±3	−0.1834	±14	0.0086
±4	0.0990	±15	−0.0081
±5	−0.0706	±16	0.0066
±6	0.0454	±17	−0.0062
±7	−0.0367	±18	0.0052
±8	0.0259	±19	−0.0051
±9	−0.0224	±20	0.0042
±10	0.0166		

$$
\begin{aligned}
m(-a) &= \cdots + b_{-5}\phi_{(+4)} + b_{-4}\phi_{(+3)} \\
&+ b_{-3}\phi_{(+2)} + b_{-2}\phi_{(+1)} + b_{-1}\phi_{(0)} + b_0\phi_{(-1)} \\
&+ b_1\phi_{(-2)} + b_2\phi_{(-3)} + b_3\phi_{(-4)} + \cdots \\
m(0) &= \cdots + b_{-4}\phi_{(+4)} + b_{-3}\phi_{(+3)} \\
&+ b_{-2}\phi_{(+2)} + b_{-1}\phi_{(+1)} + b_0\phi_{(0)} + b_1\phi_{(-1)} \\
&+ b_2\phi_{(-2)} + b_3\phi_{(-3)} + b_4\phi_{(-4)} + \cdots \\
m(a) &= \cdots + b_{-3}\phi_{(+4)} + b_{-2}\phi_{(+3)} \\
&+ b_{-1}\phi_{(+2)} + b_0\phi_{(+1)} + b_1\phi_{(0)} + b_2\phi_{(-1)} \\
&+ b_3\phi_{(-2)} + b_4\phi_{(-3)} + b_5\phi_{(-4)} + \cdots
\end{aligned}
\qquad (10)
$$

The mass on the surface at the depth D can be obtained by simple multiplications and additions.

Calculations

The gravity-anomaly values used in subsequent calculations have been read from the curve in Figure 2. This curve is not exact. There are notable differences between this and the curve obtained by G. P. Woollard (1953) across southern California.

The distance between two consecutive grid points, a, and the depth of the mass plane, D, will both be taken to be 35 km. It is well established that the earth's crust has this thickness in this area. In column 1 of Table 2 are the values of the Bouger anomalies as read from the curve in Figure 2 at 35-km intervals. Their mean is −82 mgals, and this value has been subtracted from each of the values in column 1; the results are listed in column 2. These deviations are assumed to be produced by the deviation of the thickness of the earth's crust from 35 km. Then, the mass $m(na)$ below each of the grid points has been calculated according to the formula (10). Taking the density contrast between the crustal and subcrustal materials to be 0.3, $m(na)$ is divided by this 0.3. The results give the deviation of the crustal thickness from 35 km. When these values are subtracted from 35 km, the remainder is the thick-

Table 2.—Bouguer Gravity Anomalies and Deduced Thickness of the Earth's Crust

n	x	1	2	3	4	5	6	7	8	9
0	0	18	100	−3.2	23.6	23.8	24.0	24.1	24.3	24.5
1	35	−11	71	37.6	24.5	24.3	24.0	23.8	23.5	23.3
2	70	−35	47	26.1	31.4	32.8	34.2	35.7	37.1	38.5
3	105	−53	29	36.5	34.7	34.1	33.5	32.8	32.2	31.6
4	140	−60	22	30.2	31.5	26.4	21.3	16.3	11.2	6.1
5	175	−70	12	35.9	35.7	35.1	34.5	33.8	33.2	32.6
6	210	−78	4	31.4	30.8	32.2	33.6	35.1	36.5	37.9
7	245	−110	−28	37.7	39.0	38.8	38.5	38.3	38.0	37.8
8	280	−143	−61	43.4	39.5	39.7	39.9	40.4	40.2	40.4
9	315	−175	−93	40.4	50.4	50.4	50.4	50.3	50.3	50.3
10	350	−185	−103	69.7	49.0	49.1	49.1	49.2	49.2	49.3
mean		−82			35.5	35.2	34.8	34.5	34.2	33.8

x. Distance in km from the coast line.
1. Estimated Bouguer anomalies in mgals.
2. Deviation from the mean in mgals.
3. Deduced thickness of the earth's crust, without correction.
4. Deduced thickness of the earth's crust in km, corrected for the effects of the gravity anomalies outside the area.
5. Deduced thickness of the earth's crust in km when the maximum effect of the Central Valley deposits is taken to be −20 mgals.
6. As in 5, for −40 mgals.
7. As in 5, for −60 mgals.
8. As in 5, for −80 mgals.
9. As in 5, for −100 mgals.

ness of the earth's crust below each grid point (Table 2, column 3).

In making the calculations, no considerations have been given to the effects of the gravity persists throughout the thickness the effect due to this will be as much as 100 mgals. In calculating the effect of this layer on the determined thickness of the earth's crust, the maximum

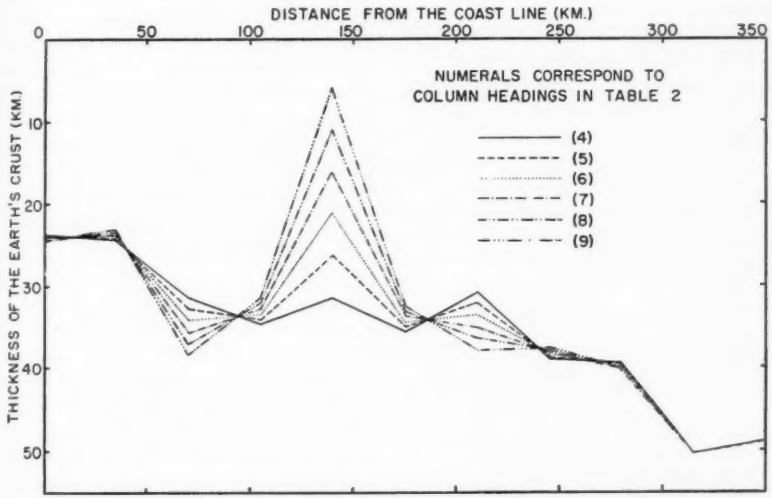

FIGURE 3.—THICKNESS OF THE EARTH'S CRUST ON VARIOUS ASSUMPTIONS FOR THE EFFECT OF THE CENTRAL VALLEY DEPOSIT

anomalies outside this area, those on the Pacific and continental sides. Natural extensions of the curve in Figure 2 toward both sides suggest that the gravity anomalies to the west of this area may be taken to be uniformly +50 mgals, while those east of it, uniformly −185 mgals. Any change in these values will cause no notable alteration in the final results, except for a few grid points located close to the boundaries of the area. Column 4 in Table 2 shows the final values obtained after corrections were made for the effects of gravity anomalies outside the area. The curve (4) in Figure 3 represents the results.

EFFECT OF THE CENTRAL VALLEY DEPOSITS

So far, no allowance has been made for the effects arising from the thick layer of deposits in the Central Valley between the Coast Range and the Sierra Nevada. The maximum thickness of the layer is almost 10 km in this area, and if the density contrast 0.3 between the materials of this layer and the basement rock negative attraction of the layer is taken as 20, 40, 60, 80, and 100 mgals. It has been assumed that the negative attraction is maximum at point 4 and that it decreases in amount linearly toward both sides until it is 0 at the points 2 and 6. The values in columns 5–9 in Table 2 are the corresponding final values of the thickness of the earth's crust. If 40 mgals or more is

TABLE 3.—DENSITY DISTRIBUTION WITHIN THE CENTRAL VALLEY DEPOSITS

Depth (km)	Density contrast	Density
0	0.30	2.50
1	0.18	2.62
2	0.11	2.69
3	0.07	2.73
4	0.04	2.76
5	0.02	2.78
6	0.02	2.78
7	0.01	2.79
8	0.01	2.79
9	0.00	2.80
10	0.00	2.80

assumed, the results show a pronounced thinning of the earth's crust below the valley, which has not been noticed by previous seismological observations. It must be concluded that the negative attraction of the material of the layer will be 30 mgals at most.

If $\Delta\rho_0$ is the density contrast of the materials of the layer and the basement rock at the earth's surface ($z = 0$), the decrease in density contrast due to compaction at any depth z may be given by

$$\Delta\rho(z) = \Delta\rho_0 e^{-kz}, \tag{11}$$

where k is a constant. The gravitational attraction due to such a layer, assuming infinite horizontal extent, is given by

$$\begin{aligned} \Delta g &= 2\pi G\Delta\rho_0 \int_0^D e^{-kz}\, dz \\ &= 2\pi G\Delta\rho_0 \frac{1 - e^{-kD}}{k}. \end{aligned} \tag{12}$$

Putting

$$\Delta g = 30 \text{ mgals} = 3 \times 10^{-2},$$

$$G = 6.7 \times 10^{-8},$$

$$\Delta\rho_0 = 0.3,$$

then

$$k = 4 \times 10^{-6}.$$

The density distribution within this layer which corresponds to this value of k is given in Table 3 for a surface density of 2.50.

Although the foregoing calculation is an inexact one, there is no doubt that the layer increases in density rapidly with depth, and that at depths of a few kilometers no appreciable density contast between this layer and the basement rocks can be detected. This agrees well with the facts observed by seismic prospectings and core samplings. About an area adjacent to the one studied here, G. P. Woollard (1953) states:

"... the mean density differential for the sedimentary columns compared to the basement complex would have to be about 0.075, a value not improbable, for below 10,000 feet the shale might well be compacted to yield values equal to if not exceeding the density of the crystallines. ..."

Conclusions

The earth's crust is about 24 km thick beneath the California coast line, and the thickness increases inland until it is about 50 km at a point 350 km from the coast line. These values are in general agreement with those obtained by Frank Press (1956). The thickness values given in Table 2 have been derived on the assumption that the density contrast between the crustal and subcrustal materials is 0.3. If another value $\Delta\rho$ is taken for the density contrast, the thickness D (Table 2) must be changed into

$$35 + (D - 35) \times \frac{0.3}{\Delta\rho}.$$

Finally, as shown in Figure 3, there are relatively steep changes in thickness at two places, one at a distance of 50 km, the other at 300 km from the coast line. Nothing definite can be said of this, however, because of the scantiness of the gravity-anomaly values used.

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DETERMINATION OF CRUSTAL STRUCTURE FROM PHASE VELOCITY OF RAYLEIGH WAVES PART I: SOUTHERN CALIFORNIA

BY FRANK PRESS

ABSTRACT

Local changes in crustal structure from variations of phase velocity of Rayleigh waves are deduced by utilizing the prolonged, sinusoidal trains of dispersed Rayleigh waves characteristic of long oceanic propagation paths. Crests and troughs of these waves can be traced across a triangular array of seismograph stations when the station separations are not more than a few wave lengths. Phase velocity and direction of approach can be determined for waves of a given period. By comparing observed phase velocity with an experimentally determined phase-velocity curve representative of the average continental crust local crustal thickness is obtained.

Application of the method to Southern California indicates the following: (1) normal crustal thickness in the Peninsular Range Province; (2) increase of mean crustal thickness by about 50 per cent in the Sierra Nevada block; (3) significant decrease in crustal thickness, possibly as much as 50 per cent in the continental borderland.

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INTRODUCTION

In the last decade knowledge of crustal[1] structure has increased markedly. Except for certain anomalous belts such as mountain chains and margins the continental crust is approximately 35 km thick everywhere. The oceanic crust is similarly uniform, having an approximate thickness of 5 km. Summaries of recent geophysical measurements of crustal

[1] "Crust" as used in this paper refers to the silicic layer bounded below by the Mohorovičić discontinuity.

structure have been given by Gutenberg (1955) and Ewing and Press (1955).

Investigations of the complex crustal structure in the anomalous belts are now of particular importance. Results of such studies will provide data which are basic for theories of evolution of continents, ocean basins, and other crustal features.

The seismic refraction method is the principal tool for investigating crustal structure. Difficulties have been encountered, however, in applying this method in regions of complex structure. Scattering and absorption of the relatively short (5 km) elastic body waves caused by the heterogeneity of regions with complex structure may account for some of these difficulties.

In this paper a method is described for determining variations in crustal structure from variations in the phase velocity of Rayleigh waves which have traversed long oceanic paths. The method is used to determine crustal thickness in the Peninsular Range province and the Sierra Nevada block in Southern California. Indications of crustal thickness in the offshore region are also obtained.

Acknowledgments

In the course of this research the author benefited from many fruitful discussions with his colleagues, Professors Benioff, Gutenberg, and Richter. Mr. John Nordquist aided with the computations and prepared the figures.

Method

A primary feature of seismograms of distant shallow focus earthquakes is the dispersed train of Rayleigh waves. Dispersion, evidenced by a variation of period with travel time, results from differences in elastic properties of the layers above and below the Mohorovičić discontinuity. The longer waves are affected by the deeper, higher-velocity mantle, hence arrive earlier than the shorter waves traveling with velocities more representative of the shallower layers. An example of dispersed Rayleigh waves recorded at Pasadena, Riverside, and Barrett from an earthquake in the Solomon Islands is shown in Figure 1. From single seismograms one can construct a curve of group velocity versus period. The procedure consists of measuring the travel time of waves of a given period and dividing this time into the epicentral distance. By repeating the process for a sequence of periods a curve is determined which may be compared with theoretical group-velocity curves constructed under different assumptions of crustal structure. In this way one can actually infer the average properties of the crust between the epicenter and seismograph station. Press and Ewing (1955) summarized results obtained by group-velocity analysis.

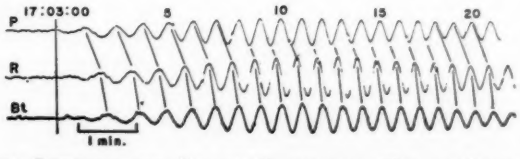

FIGURE 1.—PASADENA, RIVERSIDE, AND BARRETT SEISMOGRAMS (BENIOFF LONG PERIOD Z) FROM THE SOLOMON ISLAND EARTHQUAKE OF 26 MAY, 1955
Seismograms are aligned in time and corresponding waves are indicated

To determine local variations in crustal structure one must use the phase velocity. It can be determined, together with direction of propagation, from the difference in arrival times of individual crests and troughs recorded at three seismographs arranged in a triangular array. Phase velocity (c) is a function of peroid (T) and is related to group velocity (U) by a familiar equation:

$$U = c + kdc/dk \tag{1}$$

where $k = 2\pi/cT$.

It is important that the linear dimensions of the array be of the order of a wave length. If the separations are much smaller the arrival-time differences cannot be determined with sufficient precision. A consequence of dispersion

is the gradual increase of the period (hence the phase velocity) associated with a crest or trough. Therefore, if the separation of the elements of an array much exceeds a wave length the phase velocity cannot be considered uniform within the array. Another difficulty of large separations is the problem of identification of given crests and troughs at each of the stations. Evernden (1953, p. 338–339) reviewed the criteria for establishing the dimensions of an array.

The local phase velocity of Rayleigh waves depends on the period, the thickness of the crust, and the elastic constants of the crust and upper mantle. These parameters are related implicitly in a lengthy period equation which has been discussed by numerous authors (*see* Lee, 1932, p. 89). The principle of the method used in this paper is to interpret local variations of phase velocity for a given period in terms of changes in crustal thickness. Local variations in the elastic constants can also produce variations in phase velocity. However, recent work (Birch, 1955, p. 104; Ewing and Press, 1955, p. 3) indicates that despite the heterogeneity of materials that make up the crust there is an apparent uniformity in seismic velocity. This is especially true when the properties of the crust and underlying mantle are averaged over distances of 50–100 km which correspond to the wave lengths of the Rayleigh waves used in this study. Further corroboration of the uniformity of seismic velocities may be found in Richter's conclusion (1955, p. 194), based on data from Kern County, California, earthquakes, that the velocity of compressional waves in the silicic crust beneath the Sierras is normal. Similarly the author has found that Lg waves traverse the length of the Sierra block with velocity close to the average found for paths of continental dimensions. It therefore seems reasonable to correlate changes in phase velocity of Rayleigh waves with changes in crustal thickness.

One of two procedures can be used to relate phase velocity to crustal thickness. Theoretical phase-velocity curves for various thicknesses can be computed from the period equation for Rayleigh waves in the crust-mantle system assuming values for the elastic constants of the layers. Evernden (1954, p. 175–180) used this method in a study emphasizing not so much a determination of crustal structure as an explanation of the characteristics of Rayleigh waves.

A better procedure is to derive a phase-velocity curve from an experimentally determined group-velocity curve. If the group-velocity curve stems from Rayleigh waves which have traversed a long continental path mostly free from anomalous structures then the derived phase-velocity curve will be representative of the average continental crust. Local observations of phase velocity may then be compared with this phase-velocity curve to determine local crustal thickness referred to the average thickness of the continental crust. The latter procedure is used in this paper. It offers the advantage that in the interpretation a minimum number of assumptions is made concerning crustal structure. If local values of phase velocity are to give numerical values for crustal thickness, then it is necessary to adopt a numerical value for the average thickness of the continental crust. Recent seismic refraction studies in North America and South Africa, summarized by Gutenberg (1955), indicate that 35 km represents this value well.

A well-defined Rayleigh wave group-velocity curve was determined by Press, Ewing, and Oliver (1956) for an earthquake path from Algeria to Natal. A phase-velocity curve was determined such that it is related to the experimental group velocity curve through equation 1 in the period range 10–40 sec. Outside this period range it is related to a theoretical group-velocity curve given by Press and Ewing (1955, p. 59) for a crustal layer 35 km thick with shear velocity 3.51 km/sec., overlying a mantle with shear velocity 4.68 km/sec. This structure is concordant with the results of seismic refraction measurements. It should be noted, however, that the portion of the derived phase-velocity curve which will be used to interpret local variations in phase velocity stems from the experimental group-velocity curve for Africa.

In Figures 4–8 a series of calibrating phase-velocity curves are drawn. The curve marked 35 km is that derived from the experimental group-velocity curve for Africa. The other curves are determined by the condition valid for Rayleigh waves in layered media: for a given phase velocity a crustal thickness change pro-

duces a proportional change in the period. Thus if the average thickness of the crust of Africa is 35 km, the phase-velocity curves represent crusts with thicknesses 45, 35, 25, and 15 km respectively. For any other value of average crustal thickness in Africa, say H, the positions of the curves are unchanged but they correspond to thicknesses 45H/35, 35H/35, 25H/35, and 15H/35.

To determine variations in crustal structure from phase velocity variations it is necessary to measure phase velocity for a given period to within 0.1 km/sec. A basic feature of the method is the use of a procedure whereby this precision can be achieved. Ideally an accurate determination of phase velocity, for a given period, requires a long train of sinuosidal oscillations of constant period and amplitude. Arrival times of crests and troughs at each station of a tripartite array can then be determined accurately and in a number sufficient to obtain a suitably precise mean value. In the absence of these ideal waves use is made of Rayleigh waves whose paths include long oceanic segments. Typically, these waves are sinusoidal and exhibit slow variations in amplitude and period with time in the range 15–24 sec. (Fig. 1). These characteristics follow from the steepness of the group-velocity curve for the oceanic portion of the path (Ewing and Press, 1952, p. 322–324). It is possible to obtain as few as 3 and as many as 10 cycles with constant period and almost constant amplitude. In a sense the method uses the ocean as a spectrograph to separate the harmonic components of the initial elastic pulse so that the local phase velocity of selected components may be individually determined.

The procedure for measuring phase velocity begins with assigning an index number to each of the crests and troughs of the surface-wave train arriving at the stations of a tripartite array (Fig. 1). When the station separation is of the order of a wave length there is no difficulty in correlating the individual crests and troughs at each of the stations of the array. This correlation is readily established by aligning the three seismograms to match the early oscillations where the dispersion is most pronounced. Correlation across larger distance may also be established by allowing for stretching of the wave train with increasing distance. It is essential that seismograms from identical instruments be used in order to be certain of the correlation and to eliminate the effect of instrumental phase shift in measuring phase velocity.

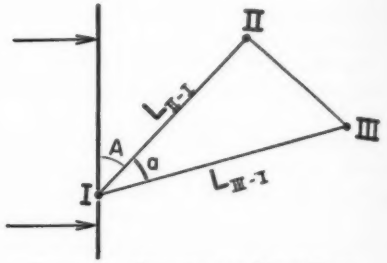

FIGURE 2.—GEOMETRY OF WAVE FRONT TRAVERSING TRIPARTITE ARRAY

Arrival times and arrival-time differences between stations are determined for the crests and troughs and tabulated against index number. These readings are then grouped by period, and the mean value of arrival-time differences for a given period is determined. Usually not less than 4 nor more than 20 arrival-time differences are available for determining the mean-time difference for a given period. If the sequence of arrival times in order of increasing time are t_I, t_{II}, t_{III}, and Δ_{III-I} and Δ_{II-I} are the mean arrival-time differences for a given period with respect to the station I, then the phase velocity c is given by the conditions:

$$c = \frac{L_{II-I} \cdot \sin A}{\Delta_{II-I}} = \frac{L_{III-I} \cdot \sin (A + a)}{\Delta_{III-I}} \qquad (2)$$

Referring to Figure 2 L_{III-I} and L_{II-I} are the distances between stations III, I and II, I, respectively, a the angle between the legs L_{II-I} and L_{III-I}, and A the angle made by the wave front and the leg L_{II-I}.

Phase velocities determined for an array are plotted against period (Figs. 4–8). Each point may be related to a value of crustal thickness by interpolating between calibrating curves. Each value of crustal thickness so determined is treated as an invariant in deriving a mean thickness and a standard error for a given array and earthquake.

DATA

Materials Used

The network of seismograph stations of the California Institute of Technology provided the basic data. The location of these stations is shown in Figure 3. It is seen that the stations effectively straddle the major structures in southern California, including the southern part of the Sierra Nevada range, the Peninsular ranges and adjacent valleys, the coastal region, and the southern portion of the San Joaquin Valley.

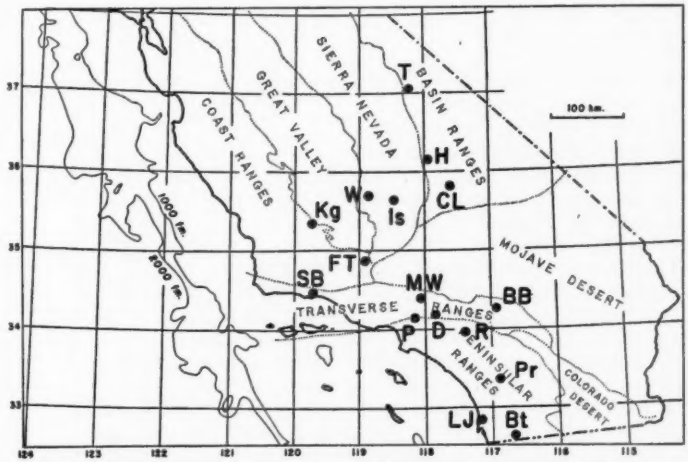

FIGURE 3.—SEISMOGRAPH NETWORK OF THE CALIFORNIA INSTITUTE OF TECHNOLOGY

Distances between stations and azimuths[2] are given in Table 1. All the stations are equipped with Benioff short-period vertical seismographs. Some stations have also one or two torsion seismographs and a long-period vertical seismograph. These three types of instruments were used in the study, the choice depending on availability of identical instruments at three stations of a desirable tripartite array and the quality of the seismograms. Four earthquakes were utilized, epicentral data being given in Table 2.

Numerical Results

General.—The numerical results of this investigation are summarized in Table 3. The first column identifies the earthquake by code number and gives the three stations of a tripartite array in order of increasing Rayleigh wave arrival time. Mean arrival-time differences are listed for a sequence of periods, followed by the number of crests and troughs used in arriving at the mean. The computed value of phase velocity c is given for each period together with both the tripartite and great circle determination of direction of approach of the wave front.

Phase-velocity values are plotted in Figures 4–8, which show also the effective region of coverage for each earthquake-array combination. Each point was used to determine a value of crustal thickness by interpolating between the calibration curves. The mean values of crustal thickness and standard errors determined for each earthquake-array combination are tabulated in the last column of Table 3.

1 Pasadena-Palomar-Big Bear; 2 Pasadena-Big Bear-Palomar.[3]—Phase velocities for these two earthquake-array combinations are plotted in Figure 4. Although the wave fronts cross the arrays in different directions, the regions covered are approximately the same, and include portions of the Transverse ranges, the

[2] In computing angle α in Equation 2 distances only were used.

[3] A number followed by names of three stations signifies a particular earthquake (Table 2) and triangular-array combination.

TABLE 1.—DISTANCE IN KM BETWEEN STATIONS, AND AZIMUTH OF STATION IN LEFT COLUMN FROM STATION IN BOTTOM ROW

BB	174.3														
	353°														
CL	358.1	185.8													
	346°	340°													
D	196.3	82.9	183.6												
	327°	265°	186°												
FT	318.7	195.0	157.7	126.6											
	319°	291°	228°	308°											
H	401.4	231.4	48.7	218.6	163.6										
	343°	336°	317°	356°	31°										
Is	368.5	211.5	82.0	174.4	93.5	71.7									
	333°	317°	256°	340°	24°	220°									
Kg	408.6	286.0	201.8	218.9	92.5	184.3	120.2								
	316°	295°	255°	306°	303°	241°	253°								
LJ	58.2	155.7	329.0	153.9		369.0									
	292°	192°	174°	160°		170°									
MW	214.3	105.4	181.4	23.9	105.3	212.2	162.0	197.2	168.4						
	323°	269°	193°	285°	133°	182°	166°	128°	334°						
P	214.4	116.4	192.3	33.5	104.3	221.4	168.2	194.7	166.1	13.6					
	319°	265°	196°	266°	140°	185°	170°	132°	329°	231°					
Pr	76.3	98.7	281.8	126.7	252.7	325.3	294.7	344.6	65.4	147.4	150.5				
	347°	177°	166°	136°	132°	162°	150°	130°	34°	131°	126°				
R	159.7	50.5	203.2	44.6	170.4	243.8	209.0	263.0	125.8	67.9	75.5	86.0			
	336°	237°	174°	116°	125°	167°	151°	124°	355°	112°	103°	326°			
SB	343.6	258.8	246.0	178.0	89.1	246.4	175.2	98.4	287.7	154.5	145.8	290.7	221.3		
	305°	275°	232°	280°	238°	220°	220°	178°	307°	279°	283°	295°	283°		
T	505.8	334.4	148.8	322.3	249.4	104.6	158.2	235.2	473.5	314.4	322.5	429.6	348.4	319.6	
	344°	339°	338°	353°	14°	347°	8°	35°	349°	357°	359°	343°	347°	25°	
W	390.2	239.5	113.6	194.2	92.9	92.9	33.7	91.6		178.7	182.7	318.1	232.1	160.6	160.2
	329°	313°	263°	331°	3°	238°	280°	63°		336°	340°	325°	325°	30°	200°
	Bt	BB	CL	D	FT	H	Is	Kg	LJ	MW	P	PR	R	SB	T

BB—Big bear
Bt—Barrett
CL—China Lake
D—Dalton
FT—Fort Tejon
H—Haiwee
Is—Isabella
Kg—King Ranch
LJ—La Jolla
MW—Mount Wilson
P—Pasadena
Pr—Palomar
R—Riverside
SB—Santa Barbara
T—Tinemaha
W—Woody

TABLE 2.—EPICENTRAL DATA

No.	Date	Origin time	Lat.	Long.	Magnitude
1	27 Feb. 1955	20:43:23	27½° S	176° W	8
2	25 Nov. 1953	17:48:52	34° N	141½° E	8¼
3	23 April 1955	18:28:47	24½° S	113° W	6¾
4	26 May 1955	16:23:10	10° S	161° E	7

Peninsular ranges, and adjacent valleys. Crustal-thickness determinations from these arrays are respectively 35 ± 1 and 36 ± 1 km, essentially the same as that of the average crust of Africa.

The wave front for earthquake 1 parallels the continental margin so that refraction effects are minimized. The mean value of the direction of approach determined by tripartite measurements falls within 1 degree of the great-circle direction between the epicenter and Pasadena.

The wave front from earthquake 2 strikes the

TABLE 3.—COMPUTATION OF PHASE VELOCITY AND DIRECTION OF APPROACH: DATA AND RESULTS

Earthquake array	Period in sec.	Δ_{II-I} (sec.)	Δ_{III-I} (sec.)	No. of crests and troughs	c km/sec.	Tripartite direction of approach in degrees W. of N.	Great circle direction of approach in degrees W. of N.	H(km)	$\bar{H}$(km)
1P, Pr, BB*	23.0	11.1	26.8	5	3.62	129°	131°	38	35 ± 1
	20.0	11.5	26.8	12	3.65	128°		32	
	18.6	9.7	26.6	7	3.55	131°		34	
	17.0	9.5	26.9	9	3.48	131°		35	
	16.2	9.9	27.4	20	3.44	131°		36	
	16.0	10.3	27.1	17	3.51	130°		32	
1W, H, T	24.8	25.8	39.6	3	3.55	131°	132°	46	47 ± 2
	22.0	30.0	39.8	4	3.42	128°		51	
	19.4	26.9	39.8	9	3.43	128°		44	
	18.4	27.5	40.2	4	3.36	128°		48	
	18.0	26.6	39.6	4	3.47	129°		38	
	16.8	28.2	41.7	10	3.28	129°		54	
1W, I, T	19.4	6.5	39.5	7	3.43	128°	132°	44	49 ± 3
	18.4	6.7	39.6	9	3.39	127°		45	
	16.8	6.7	41.8	9	3.27	129°		56	
	16.4	6.6	41.8	6	3.29	129°		50	
1P, Bt, R	23.0	1.4	12.2	8	3.77	130°	131°	31	28 ± 4
	20.0	1.2	12.5	11	3.65	130°		32	
	16.0	1.6	12.2	10	3.78	129°		22	
1Kg, W, Is	20.0	26.1	32.4	10	3.42	130°	132°	46	43 ± 3
	18.4	25.9	32.6	9	3.50	126°		37	
	16.3	27.1	33.7	15	3.30	129°		49	
	16.0	26.4	32.9	18	3.39	129°		39	
2P, BB, Pr	21.2	29.7	39.2	5	3.63	73°	65°	35	36 ± 1
	19.6	31.1	39.8	12	3.52	75°		38	
	19.0	31.1	38.9	11	3.56	77°		35	
	18.0	31.2	39.1	10	3.54	77°		34	
2P, R, Pr	24.6	20.7	39.6	6	3.63	71°	65°	41	34 ± 2
	21.2	20.9	39.2	6	3.61	74°		36	
	19.6	20.6	39.8	13	3.64	70°		32	
	19.0	20.6	38.9	11	3.66	73°		30	
	18.0	20.9	39.1	11	3.61	74°		31	
2P, Pr, Bt	23.0	39.4	51.8	10	3.73	67°	65°	33	31 ± 2
	19.6	39.8	52.6	8	3.70	65°		29	
3R, P, T	18.9	6.4	98.0	4	3.52	184°	184°	37	49 ± 4
	16.8	6.7	102.7	6	3.37	185°		42	
	15.4	6.9	104.1	10	3.32	185°		44	
	14.0	7.5	105.8	12	3.27	186°		47	
	13.3	8.5	107.5	15	3.24	188°		62	
	12.7	9.2	108.0	8	3.24	190°		59	
3Bt, R, P	18.9	38.0	44.3	4	4.00	186°	183°	18	16 ± 1
	16.8	39.0	45.8	6	3.91	188°		19	
	15.4	39.4	46.3	10	3.88	188°		18	
	14.0	39.5	47.0	12	3.91	190°		16	
	13.3	39.9	48.3	15	3.92	193°		14	
	12.7	40.1	49.3	8	3.94	196°		13	
4P, R, Bt	24.0	16.3	23.2	7	4.11	104°	103°	16	19 ± 1
	22.0	16.5	23.1	8	4.04	105°		19	
	19.3	16.9	24.4	11	3.98	105°		19	
	18.4	17.2	25.1	7	3.92	104°		20	
	17.7	17.2	24.0	12	3.87	105°		21	

* *See* Table 1 for abbreviations.

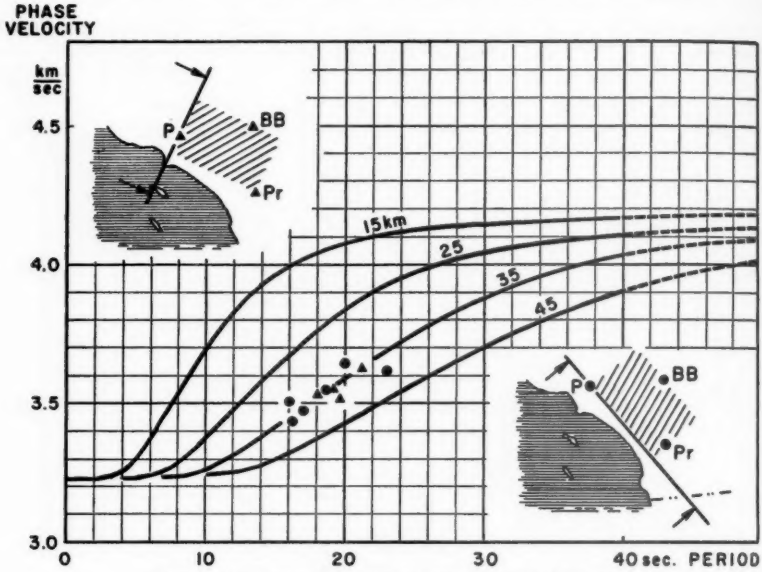

FIGURE 4.—PHASE VELOCITIES COMPUTED FOR ARRAYS
1 Pasadena-Palomar-Big Bear; 2 Palomar-Big Bear-Palomar.

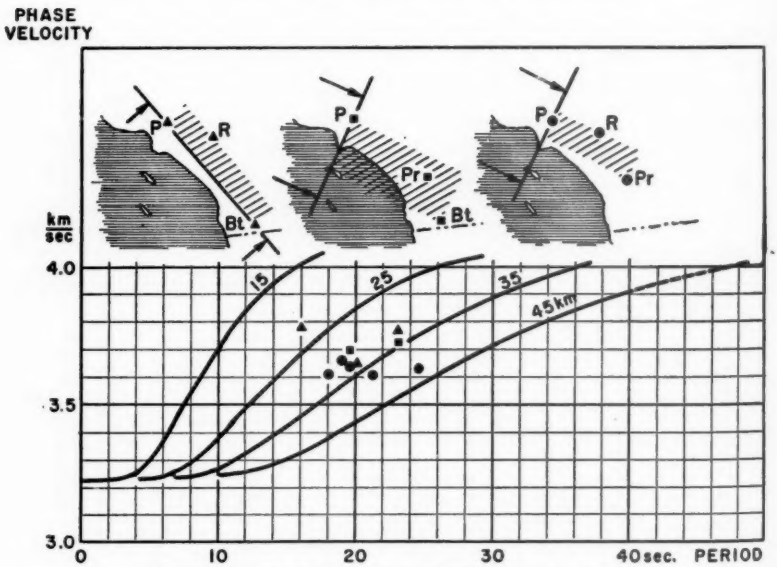

FIGURE 5.—PHASE VELOCITIES COMPUTED FOR ARRAYS
2 Pasadena-Riverside-Palomar; 1 Palomar-Barrett-Riverside; 2 Pasadena-Palomar-Barrett.

continental margin obliquely, resulting in an expected large refraction. The mean of tripartite-determined directions of approach differ by 10° from the great-circle direction. Evernden (1954, p. 161) found a similar refraction effect for waves crossing the continental margin near Berkeley.

2 Pasadena-Riverside-Palomar; 1 Pasadena-

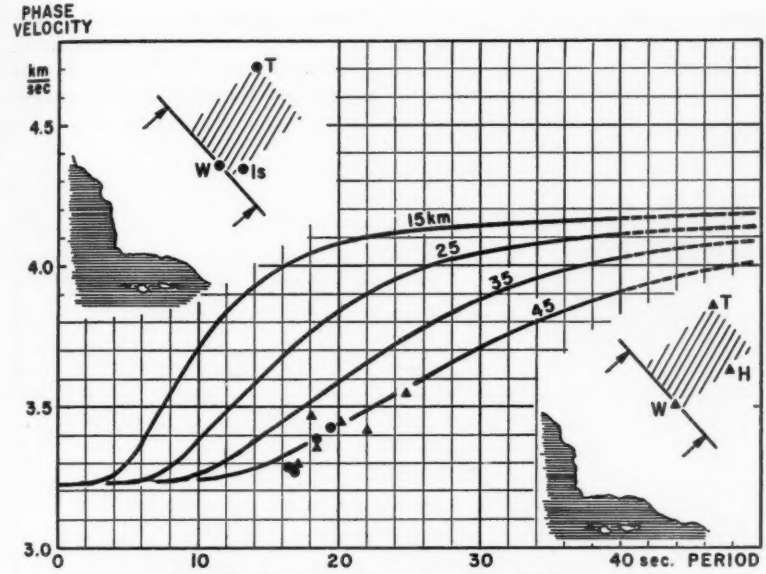

FIGURE 6.—PHASE VELOCITIES COMPUTED FOR ARRAYS
1 Woody-Haiwee-Tinemaha; 1 Woody-Isabella-Tinemaha.

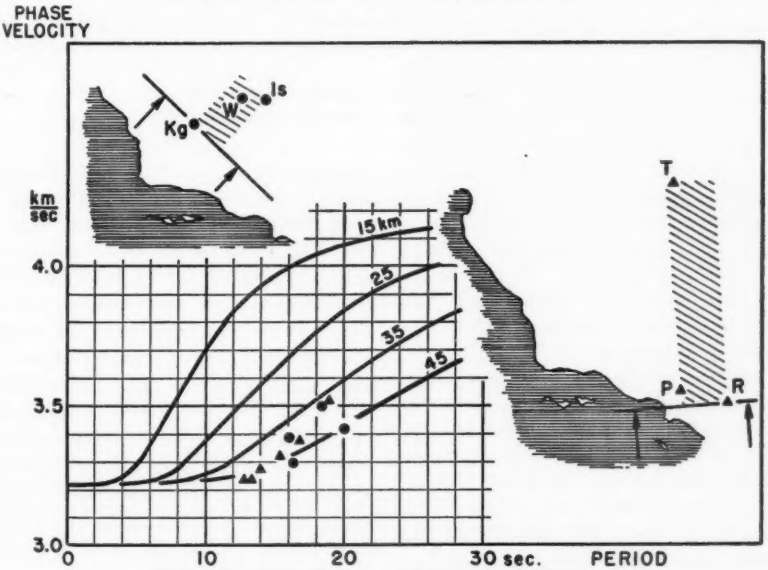

FIGURE 7.—PHASE VELOCITIES COMPUTED FOR ARRAYS
1 King Ranch-Woody-Isabella; 3 Riverside-Pasadena-Tinemaha.

Barrett-Riverside; 2 Pasadena-Palomar-Barrett. —These arrays lie in the Peninsular Range province (Fig. 5). Crustal thickness determinations are respectively 34 ± 2, 28 ± 4, 31 ± 2 km. The region covered is closer to the coast, and the data indicate a slightly thinner crust than found for the previous arrays.

1 Woody-Haiwee-Tinemaha; 1 Woody-Isa-

bella-Tinemaha.—These data apply to the southern portion of the Sierra Nevada bloc (Fig. 6). Mean thicknesses of 47 ± 2 and 49 ± 3 km are obtained, representing an increase of

to obtain offshore coverage with seismographs located on the continent, it was necessary to use long segments of wave fronts striking the continental margin obliquely. The possibility of

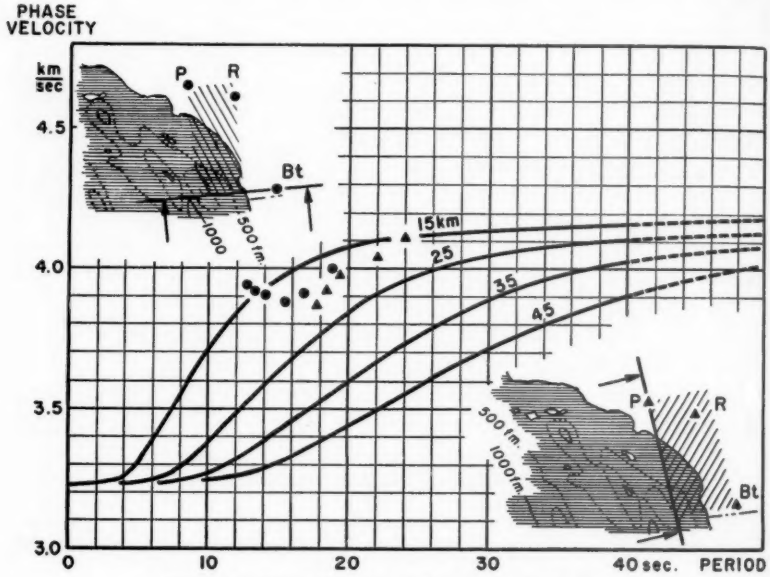

FIGURE 8.—PHASE VELOCITIES COMPUTED FOR ARRAYS
3 Barrett-Riverside-Pasadena; 4 Pasadena-Riverside-Barrett.

almost 50 per cent compared to the results for the Peninsular Range province.

1 King Ranch-Woody-Isabella.—This array is located in an area that includes the southernmost part of the San Joaquin Valley and the western slope of the Sierra Nevada block (Fig. 7). The thickness for the crust is 43 ± 3, a value intermediate between that found for the Sierra block and the average continental crust.

3 Riverside-Palomar-Tinemaha.—The stations form an elongated triangle, reducing somewhat the precision of measurement. The area covered includes parts of the Mojave Desert, the Sierra Nevada block, and Owens Valley (Fig. 7). The mean crustal thickness for this composite region is 49 ± 4 km.

3 Barrett-Riverside-Palomar; 4 Palomar-Riverside-Barrett.—These arrays were selected to provide some information about the continental shelf and borderland (Fig. 8). In order

curvature of the wave front caused by refraction effects is therefore greatest for these cases. Although the thicknesses of 16 ± 1 km and 19 ± 1 km determined for these arrays show low standard errors, a systematic error caused by wave-front curvature may be present. If the crust in the borderland region exhibited a higher velocity than normal for the continent, the thickness determination would be too small.

The data from these shore-based arrays apply to an area which includes portions of the continent and border land. The determinations suggest a crustal thickness in the borderland about half the average thickness of the continent, with the possibility of a significant systematic error.

Additional data from a seismograph station located on an offshore California island could remove the uncertainty from these results.

Discussion

Crustal structure in California reflects two major features—proximity to the continental margin on a regional basis and topographic and geologic diversity on a local basis. The main results of this study may be summarized as follows: (1) crustal thickness in the Peninsular Range provincei s close to the average value for the continental crust; (2) the crust thickens by about 50 per cent under the Sierra Nevada block; (3) the crust thins significantly, possibly as much as 50 per cent in the continental borderland. A composite cross section summarizing these results is presented in Figure 9.

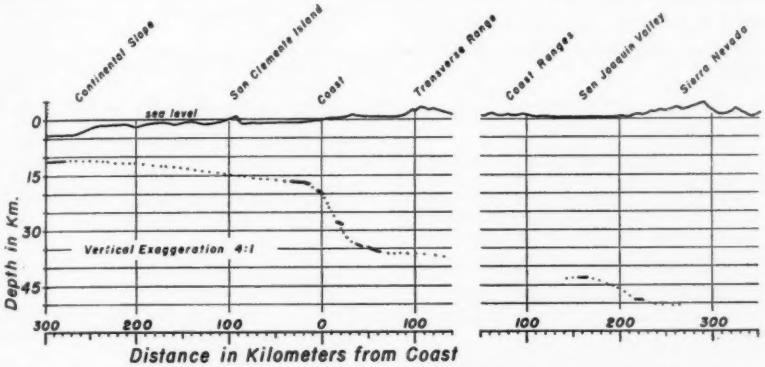

Figure 9.—Composite Cross Section of Crustal Structure in Southern California

Crustal thickness in the Peninsular Range province appears to be affected more by proximity to the continental margin than by local topographic and structural features. A gradual thinning of the crustal is indicated coastward. Viewed regionally, the crust is unaffected by topographic highs of the Transverse and Peninsular ranges.

On the other hand, a marked thickening of the crust is associated with the Sierra Nevadas. The regional nature of the crustal thickening is indicated by the value 43 km determined in an area that includes portions of the San Joaquin Valley and the Sierra block. The root found under the Sierra block is of the right order of magnitude to account for the observed negative Bouger gravity anomaly of −200 mg. (Tsuboi, 1956). One must thus conclude that the Sierra Nevada block is in approximate isostatic equilibrium.

Byerly (1938) and Gutenberg (1943) found indications of a Sierra root from the delay of the P phase. These observations could give estimates of the dimensions of the root but did not permit a direct determination.

These results together with the most recent results of seismic refraction investigations in mountains (Tatel and Tuve, 1955, p. 48–50) suggest that both compensated and uncompensated mountains occur. When the crustal structure of other mountain systems is established, the relative importance of such parameters as height, lateral extent, age, and geologic structure in determining the extent of crustal thickening under mountains may become evident.

The crust of the continental borderland is significantly thinner than the average thickness of the continent. Although the network of stations provide inadequate offshore coverage for a precise measurement, the available data suggest the possibility of a crust as thin as 15 km in the borderland.

Emery (1954, p. 107, 111) interprets the submarine geology of the borderland in terms of local block faulting and a broad downwarp. Our results together with the lesser seismic activity and the large area of the borderland suggest that if downwarping occurred, isostatic compensation has been maintained, the crust having been thinned by subcrustal flowage

(Gilluly, 1955, p. 15–16). The borderland would then represent a former continental segment being transformed to an oceanic one.

In an alternate interpretation, one more in keeping with the concept of continental growth along with circum-Pacific margin, the borderland would be a region in an intermediate stage of continental evolution, broken locally by block faulting.

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Seismological Laboratory, 220 North San Rafael Ave., Pasadena, California

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California Institute of Technology Contribution No. 756

Short Notes

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 67, PP. 1659-1660, 1 PL. DECEMBER 1956

WIND-INDUCED STONE TRACKS, PRINCE OF WALES ISLAND, ALASKA

BY C. L. SAINSBURY

The recent discussion by Stanley (1955) of the stone tracks of Racetrack Playa, California, leads the writer to record observations of another variety of stone tracks formed in the shallow water of a delta. The writer observed the tracks in 1955, during field work on Prince of Wales Island, southeastern Alaska.

The tracks are formed in water not more than 6 inches deep by stones that are dragged by attached wind-blown kelp. Stones that are partially buoyed up by attached kelp are moved along when the wind blows the buoyant kelp, forming tracks that remain in the sand of the beach as the tide ebbs. The tracks apparently form only when the kelp is blown by an offshore wind during ebb tide.

The drag tracks were formed in the littoral zone of the delta of the Thorne River, on a surface that sloped gently seaward. They were observed in the process of formation on several occasions and presumably are a fairly common feature. Plate 1 illustrates the tracks and the method of their formation.

Individual tracks, or grooves, may be as much as 1 inch deep and several inches wide; the size depends upon the size of the stone being dragged and the composition of the material of the delta. Figures 1 and 2 of Plate 1 illustrate tracks cut into a pebbly surface and show the power of the dragging stones to push smaller pebbles aside.

Figure 1 of Plate 1 illustrates the length and general parallelism of the tracks. Figure 3 of Plate 1 shows a composite track transgressing ripple marks and shows the preservation of detail that is possible. The fine lines paralleling the larger track were made by the kelp and show that the track was produced in water not more than 1–2 inches deep. The small stone on the left retains the attached kelp, but the fragment that produced the right-hand track has lost its buoyant seaweed. The largest stone fragment observed (Pl. 1, fig. 2) weighed about 2 pounds and was dragged by a fairly large kelp. Menard and Dietz (1953) have observed smaller rocks rafted long distances by kelp.

Observations of the tracks indicate that, although they are common, the conditions that lead to their creation and preservation are rather restrictive. All the tracks were formed on gentle seaward-facing slopes at ebb tide under the influence of a strong offshore wind. None was observed to form as a result of onshore winds, although it is reasonable to assume that the stones are dragged by onshore winds. The reason tracks so made are not preserved apparently is that onshore winds strong enough to move the stones have a fetch sufficient to enable them to create small waves, and under the influence of the waves the stones move along jerkily rather than continuously. Moreover, the wave action probably destroys most of the tracks formed by onshore winds.

The kelp (Pl. 1, fig. 2) contains lung-shaped air sacs that individually may displace about half a cubic inch of water, and the plant normally is firmly attached to the rock. The writer never has seen a rock floating free, suspended beneath a supporting seaweed, however, as Menard and Dietz (1953) report.

The tracks observed corresponded in orientation with wind direction. Although the Thorne River crosses the delta almost at right angles to the tracks photographed, and has a noticeable current at low-tide levels, no tracks were observed that formed by current-moved stones. The driving force of the wind probably exceeds the force of the current.

The stone tracks described here were found in the littoral zone of a small delta, presumably an environment of active sedimentation. It seems likely that stone tracks in this environment occasionally are buried beneath sediments brought down by the Thorne River during high water, thus preserving them in the geologic column, and that similar tracks may be found preserved in older sediments elsewhere. The tracks of kelp-dragged stone described here and the tracks of ice-borne stones described by Stanley would provide evidence of a shallow-water environment. The tracks show that features very similar in shape, size, and orientation can be made by diverse agents in combination, and often the role of one of the agents such as ice or seaweed is not immediately apparent.

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U. S. Geological Survey, Menlo Park, Calif.
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Publication Authorized by the Director, U. S. Geological Survey

Plate 1.—STONE TRACKS

Figure 1.—Photograph showing general features of stone tracks
Photo by C. L. Sainsbury

Figure 2.—Larger stone with attached seaweed and associated track
Photo by G. Herreid

Figure 3.—Stone track cut transverse to ripple marks
Photo by C. L. Sainsbury

FIGURE 1

FIGURE 2

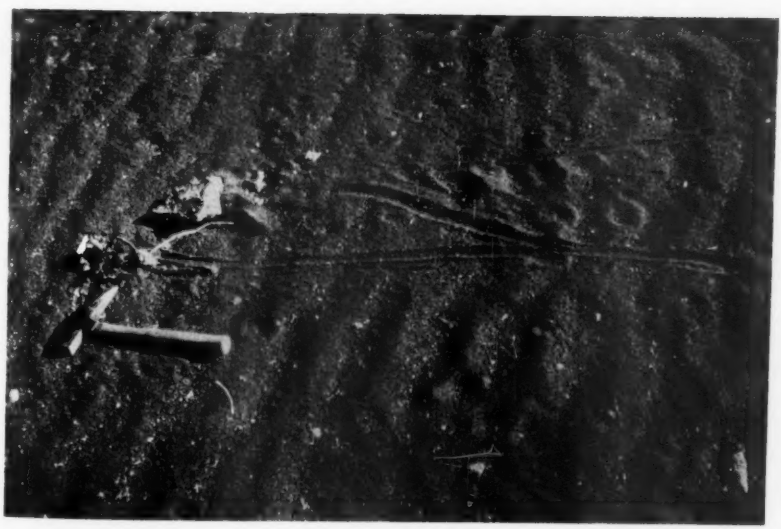

FIGURE 3

STONE TRACKS

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 67, PP. 1661–1662 DECEMBER 1956

SPHERICITY AND ROUNDNESS THROUGH THE AGES

BY PAUL D. KRYNINE

The concepts of "sphericity" and "roundness" have been generally confused by sedimentary petrographers up to 1932 or so—*i.e.*, until the works of Wadell, Russell, and others. Probably, they still are.

This confusion up to the second third of the twentieth century (or later) leads to the pessimistic outlook that, perhaps, sedimentary petrographers—as well as geologists, of course—are imbeciles. That includes me. In support of such a dim view may I present the following quotation:

"SPHERICAL AND ROUND—Also note that there is a difference between "spherical" and "round", since anything spherical is round and not vice versa; for something may be round like an egg, yet it is not spherical unless it is completely so."

In this quotation spherical refers to a perfect sphere. The quotation[1] is from Lecture I from the course of lectures ("Commentary") given by the well-known professor of the University of Paris, Robertus Anglicus. Robertus' "Commentary" (in 15 two-hour lectures, a college semester as you see) is devoted to the "exposition" and "explanation" of the famous textbook on astronomy, written by the even more celebrated professor, also of the University of Paris, Johannes Sacrobosco and entitled "The Sphere".[2]

And when did Robertus Anglicus differentiate between sphericity and roundness? In 1271!!!!!

[1] The original Latin goes like this: "Item nota quod differentia est inter spericum et rotundum, quoniam omne spericum est rotundum et non econtra, nam est aliquid rotundum sicut ovum, non tamen est spericum nisi fuerit omnino spericum". The English quotation is on page 201; the Latin one on page 145.

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Thorndike, Lynn, 1948, The *Sphere* of Sacrobosco and its commentators: Chicago, Univ. Chicago Press, 496 p. *Note:* "The Sphere" of Sacrobosco proper is on p. 76–117 (full Latin text) and on p. 118–142 (English translation). The Commentary of Robertus Anglicus is on p. 143–198 (full Latin text) and on p. 199–246 (English translation).

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MANUSCRIPT RECEIVED BY THE SECRETARY OF THE SOCIETY, JULY 5, 1956

[2] "*The Sphere*" is a veritable marvel of lucidity and conciseness. It is highly recommended to the attention of all textbook writers.

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of
The Geological Society of America

VOLUME 67 December 1956 NUMBER 12, PART 2

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ABSTRACTS OF PAPERS SUBMITTED FOR THE MEETING IN MINNEAPOLIS, MINNESOTA, OCTOBER 31–NOVEMBER 2, 1956

STRUCTURAL STUDIES BASED ON GRAVIMETRIC AND GEOLOGIC DATA IN EAST-CENTRAL MINNESOTA

Budd B. Adams
Department of Geology, University of Wisconsin, Madison 6, Wis.

Structural studies based on geologic information and the results of gravity measurements over 15 counties in Minnesota at the west end of Lake Superior are presented. The area extends from the southern edge of the Giants Range to 20 miles south of Mille Lacs Lake and approximately 30 miles west of the Cuyuna Range. Trends in Bouguer anomaly contours exhibit definite northeast to southeast trends in the vicinity of the Cuyuna Range. Probable extensions of the range appear to continue in a more southerly direction on the west end of the range and swing to the east on the east end. Possible affinities of structure in the Clouquet-Thompson area with the Cuyuna are discussed. On the southern edge of the Giants Range the Virginia anticline is a well-defined gravity high. The extension of the anomaly to the southwest and other related anomalies continuing in the same direction suggest that the structural habit is similar along most of the southern border of the range.

Using the gravimetric data along with structural information from drill holes and outcrops in the mining districts, an attempt is made to establish generalized structure sections across the region.

GEOCHEMISTRY OF THE ACTINIDES AS A POSSIBLE CLUE IN INTERPRETING THE DEVELOPMENT OF THE EARTH'S ATMOSPHERE

John A. S. Adams and Richard Pliler
Department of Geology, The Rice Institute, Houston, Texas

The ratios of thorium to uranium in sedimentary and other rocks have been compiled and augmented by scores of new determinations. The thorium/uranium ratio in most igneous rocks and meteorites is between 2.5 and 5 by weight. Limestones and black shales have a markedly lower ratio of less than 0.5. Highly weathered sediments commonly have a thorium to uranium ratio of more than 10. The ratios in different sedimentary rocks can be explained in large part by the greater solubility of uranium relative to thorium under oxidizing conditions.

If weathering under the early Precambrian atmosphere did not oxidize uranium, a much smaller range of thorium/uranium ratios might be expected. Thus, thorium/uranium ratios in sedimentary rocks may provide an oxygen indicator for the Precambrian atmosphere. The original thorium/uranium ratios in a sediment may be preserved better than the ferrous/ferric ratios that have been used as an oxygen indicator. The range of thorium/uranium ratios in Precambrian sediments is being determined. Several Precambrian limestones are markedly low in uranium (under 0.05 parts per million), which is another possible consequence of nonoxidizing conditions during deposition.

DORE LAKE COMPLEX, PETROGRAPHY AND METAMORPHISM

Gilles Allard
Chibougamau Mining & Smelting Co. Inc., Chibougamau, Quebec

The Dore Lake Complex is located in the Chibougamau mining district, Quebec. The Complex, of Precambrian age, is 27 miles long and over 10,000 feet thick. It intrudes volcanic rocks and originally had a flat sheetlike shape but has been arched by a younger granitic batholith (The Chibougamau Lake Complex) made up of diorites, quartz diorites, granodiorites and granites.

The complex is similar to other stratiform sheets except that the whole mass had been subjected

to metamorphism of the greenschist facies. Anorthosite originally formed the main layer of the mass, but it is now meta-anorthosite, a mixture of albite and zoisite or clinozoisite. Relic anorthosite patches indicate a very calcic plagioclase (An_{90}) originally.

The meta-anorthosite grades into a transition zone (gabbroic meta-anorthosite and anorthositic metagabbro) which is overlain by magnetite-rich metapyroxenite (?) and metapyroxenite. This in turn is overlain by metagabbro, hornblende diorite, magnetite diorite, porphyritic diorite and granophyre. Layering is excellent and foliation is well developed in a few layers.

The area is transected by two major sets of faults, a northeast-trending group, parallel to the Grenville front, 15 miles away to the southeast, and southeast-striking group. The shears of the second group are commonly mineralized and copper is being mined along six of these zones. The main ore zones found occur within the anorthosite member of the Dore Lake Complex.

AGUA BLANCA FAULT—A MAJOR TRANSVERSE STRUCTURE OF NORTHERN BAJA CALIFORNIA, MEXICO

Clarence R. Allen, Leon T. Silver, and Francis G. Stehli
California Institute of Technology, Pasadena, Calif.

The Agua Blanca fault, a major strike-slip fracture zone at least 80 miles in length, cuts transversely across the Baja California peninsula about 70 miles south of the international border. Geographic features delineating the fault trace are, from west to east: Punta Banda, Santa Tomas Valley, Agua Blanca Valley, San Vicente River, Trinidad Valley, and possibly San Matias Pass. Recent scarps, fault-line valleys, shutterridges, rift topography, ground-water damming, and a quarter-mile-wide breccia zone are characteristic features. These are particularly well shown in Agua Blanca Valley (31° 29′ N., 116° 11′ W.), which is designated as the type locality.

Both the physiographic expression of the fault and the evidences of recent right-handed strike-slip displacement are remarkably similar to features of the San Andreas fault in California, but the average trend of N. 68° W. is at a distinct angle to the San Andreas fault zone and the regional tectonic grain. Right-handed stream offsets of 150–200 feet are common in Agua Blanca Valley, and similar displacements of at least 900 feet are indicated farther west near La Grulla. Earlier strike-slip movements, possibly large, are suggested by the alternation of north- and south-facing scarps and by the juxtaposition of varying rock types.

A major branch of the Agua Blanca fault diverges westward along the south side of Santo Tomas Valley for at least 14 miles and is particularly well marked by scarplets, springs, and triangular facets near Santo Tomas village.

ACTINOLITE AT IRON MOUNTAIN, MISSOURI*

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This is the first published analysis of the fibrous mineral at Iron Mountain, Missouri, that has been called amiphibole or tremolite by previous investigators. The analyzed material, which is free from stains and impurities, is from a block 1 by 2 by 4 feet, collected at the Big Cut. The amphibole is gray, forms radiating groups of columns 1–2 inches long and from ⅛ to ⅜ inch wide, and has the chemical composition of actinolite: SiO_2 58.72%, Al_2O_3 2.02, TiO_2 0.28, Fe_2O_3 1.76, FeO 9.68, MnO 1.63, CaO 10.30, MgO 13.25, H_2O 1.74, Na_2O 0.23, K_2O 0.02, total 99.63. It is optically negative, has indices of refraction $\gamma = 1.658$, $\beta = 1.647$, $\alpha = 1.631$; $2V = 80°$; $Z_A c = 16°$; pleochroism X = colorless, Y = yellow-green, Z = blue-green. These indices of refraction are slightly higher than

* Publication authorized by the Director, U. S. Geological Survey

those reported by us in 1952 for specimens of this mineral which were called actinolite on the basis of optical data but which were unsatisfactory for chemical analyses. The actinolite at Iron Mountain was formed by uralitization of salite, and many specimens are partly salite and partly actinolite. Calcite, dolomite, quartz, hematite, and fluorite locally replace actinolite.

CONTRIBUTION ON THE HECTOR, CALIFORNIA BENTONITE DEPOSIT

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The unique Hector bentonite occurs along a northwest-trending fault zone for a distance of about 5 miles. Hot springs emanating along this zone deposited travertine in a then-existing lake in which sands, marls, and acid pyroclastics also were being deposited. The tuff lying on the travertine benches was altered to saponite by siliceous solutions containing Li, F, and Cl in the last stages of hot-spring activity with the Mg being extracted from the lake water. Zeolites, representing alteration of the tuff when the springs were inactive, are found both below (analcime) and above (analcime and heulandite) the bentonite bed.

The amount of travertine decreases to the northwest as does the content of Li, F, Cl, and Mg in the clay which approaches an aluminum montmorillonite composition. In a restricted basin where magnesium is available, acid solutions from hot springs apparently produce a chemical system which forms a trioctahedral bentonite preferentially to a dioctahedral variety even though the parent material approximates the chemical composition of montmorillonite.

Minor faults have produced gouge zones and small downward displacements of the irregular bentonite lenses on the southwest side of the main fault. Located in a valley of low relief, the dominant structural feature of the deposit is the high developed by the deposition of sediments and pyroclastics on the travertine benches. River gravels and muds, and a basalt flow in places, unconformably overlie the series.

CLASSIFICATION OF THE PENTAMERACEA*

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The superfamily Pentameracea is a small group of brachiopods comprising 30 genera, including such questionable representatives as *Zdimir*. Their known range is Middle Ordovician to Upper Devonian, but they are common only in Middle Silurian to Lower Devonian strata.

The division into families and subfamilies is based primarily upon the internal structure of the brachial valve. Four families are recognized: (1) Parallelelasmatidae, with long subparallel plates defining a deep notothyrial cavity; (2) Pentameridae, characterized by tripartite or quadripartite brachial plates extending forward to enclose the muscle field; this family is subdivided into three subfamilies—Pentamerinae, Gypidulinae, and Pentameroidinae; (3) Stricklandiidae, characterized by abbreviated brachial plates that do not enclose the muscle field; (4) Enantiosphenidae, known only from *Enantiosphen*, a genus unique among the Pentameracea in having a loop.

The oldest known representative is *Parallelelasma* from the Pratt Ferry formation of Alabama. The Pentameracea are rare in the Ordovician, begin to expland in the Early Silurian, and by Middle Silurian all three subfamilies of the Pentameridae are present, as well as the Stricklandiidae. In the Middle Devonian they are reduced but continue into the late Devonian; both *Sieberella* and *Gypidula* are present in the Senecan. The superfamily Enantiosphenidae is known only from the Middle Devonian of Great Britain and Germany; the quadripartite (?) plate structure suggests a relationship with the Pentameroidinae; however, the two cannot be closely connected in time as the latter subfamily is known only from the Silurian.

* Approved by Director, Oklahoma Geological Survey

LIMITING PARAMETERS IN THE MAGNETIC INTERPRETATION OF A GEOLOGIC STRUCTURE

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A prominent aeromagnetic anomaly in Randolph County, Indiana, suggests the existence of a dikelike structure within the Precambrian basement. Because of the ambiguity in magnetic interpretation, a unique solution for the parameters (depth, geometric configuration, and magnetic susceptibility of the anomaly-producing mass) is impossible. However, it is possible to indicate a range of plausible values for each parameter.

In Randolph County the depth to the Precambrian is known to be about 3000 feet below the surface. Consequently, limits need be set only on the width, dip angle, and susceptibility contrast of the assumed dike. The limiting values are determined graphically. Theoretical anomalies over the postulated dike are computed for different dike widths, dip angles, and susceptibility contrasts. The computed profiles are fitted to an observed magnetic profile flown perpendicular to the strike of the feature. Numerical values for the "goodness of fit" are calculated using the statistical method of sums of squares.

Two plots, one for the index of goodness of fit and the other for susceptibility as functions of dip angle and dike width, are made to show the interdependence of the variables and the plausible range of each. The contoured map of goodness of fit shows that the range of best fit is between dip angles of 40° to 60° and dike widths of 1000 to 4000 feet. The contoured map of the susceptibility contrast, translated into percentage of magnetite, shows that this parameter is not as limiting as either the dip angle or dike width.

CRYSTAL STRUCTURE OF LIEBIGITE

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Chemical analysis of synthetic liebigite shows that the formula is $Ca_2UO_2(CO_3)_3 \cdot 10\text{-}11H_2O$. The previously accepted formula, $Ca_2U(CO_3)_4 \cdot 10H_2O$, is incorrect; all the uranium is in the hexavalent state. The space group is orthorhombic, *Bba*2 (C_{2v}^{17}); $a = 16.74$ A, $b = 17.54$, $c = 13.72$; $Z = 8$. The crystal structure of liebigite has been determined by direct x-ray methods. Visually estimated intensity values, corrected for absorption, were used to obtain Patterson and electron-density projections on (001) and (010). The structure consists of discrete $UO_2(CO_3)_3^{-4}$ complexes in which three CO_3^{-2} groups lie in a plane perpendicular to the linear UO_2^{+2} ion; these planes are all nearly parallel to [100] and are tilted about 45° with respect to (001). Calcium ions bond the complexes together into slablike units parallel to (010), between which water molecules are packed. The structure is correlated with chemical and optical properties.

MANKATO DRIFT IN THE LOWER FRASER VALLEY OF BRITISH COLUMBIA, CANADA*

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Recent C-14 datings on wood obtained from the base of a till found in the upper part of the Lower Fraser Valley of British Columbia indicate an age of 11,300 ± 300 years suggesting that

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the last ice advance was during the Mankato subage. This ice sheet was not nearly so extensive as pre-Mankato ice sheets, and the author believes that Mankato glaciation in southwestern British Columbia consisted of valley glaciation only. The Lower Fraser Valley extends eastward from the sea about 80 miles, and the Mankato ice sheet advanced southwestward from the Coast and Cascade Mountains and approximately half this distance terminating a few miles south of the Canada-United States boundary. The ice sheet immediately prior to the Mankato was of continental proportions and advanced several hundred miles south of the boundary. Evidence suggests that the Mankato valley glacier in its early advance stage was very similar to some of the present-day coastal glaciers in Alaska—that is, it terminated in the sea and deposited glaciomarine drift in front of and beneath the ice. During the initial advance of the ice the sea stood 600 feet or more higher than at present. As the land rose the glacier advanced and retreated across the glaciomarine drift depositing normal glacial deposits. In the final stage of retreat the Fraser River apparently was diverted from its channel 20 miles south of the boundary to its present channel.

SUBSOLIDUS RELATIONS IN THE SYSTEM FeS—FeS_2

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Solid-state reactions between pyrrhotite and pyrite were studied from 300°C to 675°C at sulfur pressures ranging from a few mm Hg to 1 atm., respectively. At the latter temperature and pressure pyrite breaks down to pyrrhotite and sulfur. The pyrrhotite-sulfur relationship was investigated up to 800°C where the sulfur pressure was about 60 atm. All runs were made in evacuated and sealed silica glass tubes.

Pyrrhotites coexisting in equilibrium with pyrite showed an increasing amount of iron omission with increasing temperature. At 520°C, 600°C, and 675°C the compositions were 46.40, 45.92, and 45.20 mol per cent Fe, respectively. Pyrrhotites in equilibrium with sulfur showed decreasing amount of iron omission with increasing temperature; the compositions at 800°C 46.00 mol per cent Fe.

Pyrrhotite compositions were determined rapidly and accurately by x-ray powder diffraction methods. The determined $(102)_\alpha$ d values varied appreciably as a function of composition from d = 2.091 Å for stoichiometric FeS to d = 2.052 Å for Fe_6S_7. The precision attained was ±0.05 mol per cent Fe.

Pyrite formed in equilibrium with pyrrhotite at temperatures from 300°C to 675°C showed no detectable change in its unit cell dimensions (a = 5.419 ± 0.002 Å), indicating that pyrite has no, or very limited, ability to dissolve pyrrhotite in its lattice.

The results obtained demonstrate that the composition of the pyrrhotite mix crystals formed in equilibrium with pyrite varies sufficiently with temperature to provide a sensitive temperature scale suitable for application to natural pyrrhotite-pyrite assemblages.

ORGANIC EXTRACTIVES FROM PRECAMBRIAN CARBONACEOUS SEDIMENTS

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In efforts to secure chemical evidence of the biogenic origin of certain coal-like sediments from Precambrian rocks of the Canadian Shield a series of organic compounds has been obtained by alkali and acid-extraction techniques from sediments of Huronian age. Anthracitic coal from the Michigamme slates (Upper Huronian) of Michigan has yielded relatively large amounts of highly

pigmented compounds whose fluorescence, absorption spectra, and other physical and chemical properties resemble those of "regenerated humic acids" such as may be obtained from Paleozoic coals. Anthraxolite and black cherts from the Gunflint formation of Middle (?) Huronian age of Canada have yielded smaller amounts of similar extractives. The associated black shales and slates, in which the more nearly pure carbonaceous sediments are interbedded, are devoid of extractives. There is evidence of porphyrins or porphyrin derivatives in certain Precambrian coally sediments. Studies are in progress to determine more precisely the chemical nature of the organic extractives.

GRAVITY SURVEYING AS A METHOD FOR DETERMINING THE RELATIONSHIP BETWEEN BEDROCK AND ICE-SURFACE TOPOGRAPHIES OF AN ICE CAP

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During the summers of 1953 and 1954 the U. S. Geological Survey, on behalf of the U. S. Army Transportation Corps and the Snow, Ice, and Permafrost Research Establishment, made a gravity survey of part of the Greenland Ice Cap near Thule. The work primarily supported glaciological investigations, and emphasis was placed on covering two areas near the margin of the Ice Cap. Because serious errors in measurements of ice thickness can result from gravity surveys where gradients normal to the profiles are unknown, emphasis was placed on obtaining an approximate gravity contour map. The gravimeter was transported primarily by weasel, and all elevations were obtained by altimetry.

Contour maps of the bedrock and ice surfaces show that the two surfaces have somewhat similar forms, but the ice topography is much subdued and is influenced by the direction and velocity of ice movement. Where the ice is less than 1500 feet thick the ice-surface relief may be as much as one-tenth of the bedrock relief, but where the ice is more than 3000 feet thick the ice-surface relief is almost imperceptible. The crests of ice-surface hills are commonly displaced from the underlying bedrock crests by as much as 0.3 mile toward the direction from which the ice is flowing. Not all ice-surface valleys overlie bedrock valleys; near steep slopes slight ice-surface valleys may overlie bedrock ridges.

LIMITATIONS ON THE POSSIBLE COMPOSITION OF THE ORE-FORMING FLUID

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The activity ratios of various important anions ($S^=$, $CO_3^=$, $SO_4^=$, OH^-, F^-, and Cl^-) in hydrothermal solutions at the time of deposition are evaluated using a simple thermodynamic technique. The ratios are interpreted in the light of the mineralogy of ore deposits, and limits are placed on the variability of each ratio in hydrothermal solutions. All the calculations are made for 25°C, and cautious extrapolation to higher temperatures seems justified; however, additional data for elevated temperatures and pressures are needed before more than approximate values can be assigned to these ratios in the ore-forming fluid.

The calculated partial pressure of CO_2 in the ore fluid is generally less than 1 atm., which suggests that a dense CO_2 phase cannot be considered an important ore fluid for most deposits. The calculated partial pressure of H_2S is usually less than 10^{-4} atm., which makes it extremely difficult to defend the theory that metals (other than the easily complexible mercury, arsenic, antimony, and perhaps gold and silver) are transported in quantity as complex sulfides or hydrosulfides. The sulfate-to-sulfide ratio is such that the oxidation potential at the time of deposition is defined by the following equation: Eh (in volts) $= 0.22 \pm 0.04 - 0.059$ pH.

REGIONAL STUDY OF THE MINERALOGY AND PETROLOGY OF THE CHATTANOOGA SHALE

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A detailed minerologic and petrographic investigation of the Gassaway member of the Chattanooga formation covering the area from northern Tennessee to Alabama has established the dependence of the uranium concentration on the composition of this shale.

The variation in the areal distribution of uranium is a reflection of the regional variation in the major shale constituents. There is no association between uranium and quartz grain size, orientation of micaceous minerals, or bedding except as these textural features vary in response to change in composition.

Bivariate correlation coefficients calculated from the mineralogical and chemical analyses of 136 samples from nine drill cores show the uranium to be directly correlated with carbon, inversely correlated with the silicate minerals, and independent of the pyrite. These simple relationships are complicated by a direct pyrite-carbon correlation. The absence of high correlation coefficients indicates that no one constituent is the source of or host for the uranium, but rather that the element was precipitated from a sea which varied little in uranium concentration throughout Gassaway time.

Multiple and partial correlation statistics indicate that, in the Chattanooga sea, the environment conducive to the accumulation and preservation of carbon also led to the precipitation of uranium, the retention of the silicate minerals, and the authigenic growth of pyrite. The very presence of pyrite, however, appears to have inhibited the precipitation of uranium, whereas the silicates acted only as a diluent.

REGIONAL AEROMAGNETIC STUDY OF THE MESABI DISTRICT, MINNESOTA

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Aeromagnetic maps of the Mesabi District, Minnesota, published by the U. S. Geological Survey, show regional magnetic trends that can be correlated with the positions of magnetite-rich members within the Biwabik iron formation. Magnetic lows are correlated with the position of major oxidized areas of the mines. Over the westernmost Mesabi the rock magnetization decreases as both the thickness and the magnetic-iron content of the cherty members diminish westward. Interpretations indicate that magnetic members within the Biwabik extend for some distance downdip from exposures in the open-pit mines. A part of the eastern Mesabi is magnetized in a direction at variance to the earth's magnetic field and gives pronounced negative anomalies.

There is geophysical evidence that the Giants Range granite extends at least 50 miles southwest of Grand Rapids. This conclusion is based in part on the contrast between the complex magnetic pattern over the granitic rocks and the simple pattern over the Virginia slate (argillite) to the south. Some quantitative interpretations may be made where the available data permit. For example, depths to magnetic rocks beneath the Virginia slate are computed to be on the order of 8000 feet.

DIFFERENTIATION DUE TO SHEARING

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A model based upon differentiation due to shearing is proposed to explain the common location of the stratiform ultrabasic rocks in the zone of high pressure and strong shearing stress along the

flanks of folds and the associated serpentine in the low-pressure area along the crest of the fold. The stratiform ultrabasic rocks are viewed as residual deposits in a depleted area.

During progressive metamorphism, steadily increasing stress will be followed by failure because of rupture and/or recrystallization. The release of stress following shearing will permit transitory "low" pressure zones to exist along the uneven surface. Minerals, such as quartz, with the largest volume thermal expansion, will be most readily able to break free, expand, and migrate into the low-pressure zones. The energy derived from friction in the shear zone can promote a crystal breakdown such that the differentiating trend is toward a decrease in volume.

The low-pressure area in the structure will favor volume increase reactions and may therefore be a scene of enrichment. Volume-change reactions result from and conform to the structure; consequently serpentine masses do not cause a distortion of the structure.

The influence of shearing stress and pressure in determining the new mineral assemblage is of more importance in controlling the composition than in forcing a new crystal suite to grow from an unchanging composition to meet new density requirements. The new mineral assemblage contains whichever minerals can grow under the pressure and temperature conditions for the new composition.

MICROFOSSIL ZONES IN CRETACEOUS ROCKS OF NORTHERN ALASKA

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A study of several thousand outcrop and well samples obtained during the Navy's oil exploration in northern Alaska demonstrates traceable microfossil zones within Cretaceous strata (early Albian to Campanian). In the lower part of the Torok and Oumalik formations (Albian) a meager microfauna is characterized by *Dorothia chadlerensis* Tappan and pyritic casts of the radiolarian *Lithocampe?* sp., whereas the laterally equivalent Fortress Mountain formation is distinguished by *Verneuilinoides tailleuri* Tappan. The upper 2000 feet of the Torok formation, the overlying Tuktu and Grandstand formations, and most of the Topagoruk formation are marked by the *Verneuilinoides borealis* faunal zone (middle to late Albian). This extensive foraminiferal zone contains about 60 species, including some excellent local markers. A zone of *Gaudryina* and *Trochammina* marks the Ninuluk formation (Cenomanian).

The lower part of the Seabee formation (Turonian) has a varied fauna, although many of the species range throughout the Colville group (Upper Cretaceous). Distinctive planktonic Foraminifera (*Gümbelina*, "*Globigerina*") in upper beds in core tests at Cape Simpson correlate these strata with Turonian beds of Alberta, northwestern United States, and Texas. *Pseudociavulina hastata* (Cushman) and *Arenobulimina torula* Tappan are restricted to the Ayiyak member; pyritic casts of a medially depressed discoidal radiolarian (*Zonodiscus* sp.) occur both in Ayiyak and undifferentiated upper beds of the Seabee. *Eoeponidella strombodes* Tappan distinguishes the Sentinel Hill or upper member of the Schrader Bluff formation (Senonian); a prolific radiolarian fauna was found in Fish Creek test well 1 in the Barrow Trail or middle member.

GRAPTOLITES FROM THE MARATHON REGION, WEST TEXAS

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The 2000-foot section of Ordovician limestone and shale in the Marathon region, Texas, has yielded graptolites throughout, and a series of zones has been erected. Zonal assemblages are similar

to those of corresponding Australian rocks rather than European. Correlations based on graptolites are as follows:

Marathon formation is equivalent to the Lancefieldian, Bendigonian, and Chewtonian of Australia, and to the middle and upper Tremadocian, Arenigian, and lower Llanvirnian of Britain. Deepkill zones 1 and 2, and Levis zones A, B, and C (Raymond) are correlated with middle and upper Marathon. The McKenzie Hill, Cool Creek, Kindblade, West Spring Creek, and Joins are correlated with the Marathon.

Alsate shale and lower Fort Pena formation are equivalent to the Castlemainian and Yapeen of Australia and the upper Llanvirnian of Britain. Deepkill zone 3 and Levis zone D are probable correlatives.

Upper Fort Pena is equivalent to the Middle Ordovician of Australia and the Llandeilian of Britain. The Oil Creek and Mclish are correlated with the Alsate and Fort Pena.

Woods Hollow shale is equivalent to the Gisbornian of Australia and to the lower Caradocian of Britain. Normanskill, lower and middle Womble, and Tulip Creek and part of the Bromide are correlated with the Woods Hollow.

Maravillas formation is equivalent to the Eastonian and Bolindian of Australia and middle and upper Caradocian and Ashgillian of Britain. The Canajoharie, Utica, Whetstone Gulf, upper Bromide and Viola, and upper Womble and Bigfork are correlated with the lower and middle Maravillas. Polk Creek and Sylvan are correlatives of the upper Maravillas.

SULFO-SELENIDES OF MERCURY

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The sulfo-selenides of mercury form a complete isomorphous series defined by the diadochy of sulfur and selenium. This series is here denoted as the metacinnabar series and includes the minerals metacinnabar, onofrite, and tiemannite. Hartwig has shown that these minerals are isostructural crystallizing in the $F\bar{4}3m$ space group. *X*-ray-fluorescence analyses of some 50 specimens establishes the regular variation in composition from metacinnabar (HgS) to tiemannite (HgSe). Unit-cell dimension, Knoop hardness, and specific gravity vary linearly with composition from $a_0 = 5.853$ Å; $G_{(measured)} = 7.65$; $H_{(Knoop)} = 75$ in metacinnabar to $a_0 = 6.073$ Å; $G_{(measured)} = 8.21$; $H_{(Knoop)} = 20$ in tiemannite.

The demonstrated continuous change in composition suggests a revision of the classification presented in Dana. The following classification is proposed:

Metacinnabar Series	Hg(S,Se)
Metacinnabar	$HgS \rightarrow HgS_{80}HgSe_{20}$
Onofrite	$HgS_{80}HgSe_{20} \rightarrow HgS_{20}HgSe_{80}$
Tiemannite	$HgS_{20}HgSe_{80} \rightarrow HgSe$

The series is found in its compositional entirety at Marysvale, Utah.

Pyrosynthetic studies and analyses of specimens of co-existing cinnabar and onofrite from Marysvale indicate that selenium is unable to replace sulfur in the cinnabar structure except for possible trace amounts. It is proposed that the distribution of selenium between cinnabar and metacinnabar is related to differences in bond type. Aurivillius states that the shortest Hg—S bonds in cinnabar appear to be of the diagonal covalent (sp) type. The Hg—(S, Se) bonds of the metacinnabar series are of the tetrahedral covalent (sp^3) type. Telkes' electrical-resistivity data indicate appreciably greater metallic character of the HgS bonds in metacinnabar, and that metallic character increases with increasing selenium content.

RELATIONSHIP OF VEIN COLOR TO MINOR-ELEMENT CONTENT OF SOME URANIUM-BEARING "SILICEOUS REEF" VEINS IN THE BOULDER BATHOLITH, MONTANA

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Vein quartz from four uranium-bearing deposits in the Boulder batholith, Montana, is of interest for its fine grain size and range of color from light gray to black. The color is due to minute inclusions of opaque minerals, chiefly pyrite, galena, sphalerite, tetrahedrite, and pitchblende, and its wide range is attributed to variation in size and concentration of the inclusions.

Semiquantitative spectrographic analyses of 83 vein-quartz samples were made for 25 elements found to be generally present. In most cases, the darker the vein quartz, the higher the content of those elements usually occurring in opaque vein minerals: Ag, As, Co, Fe, Mo, Ni, Pb, Sb, U, and Zn. Elements which showed no significant correlation with vein color are Al, B, Be, Ca, Cr, Cs, Ga, Ge, Mg, Na, P, Sr, Ti, V, and Zr.

Examination of vein-quartz sections indicated that pitchblende commonly is associated with the sulfide minerals. To test this association, the variation in uranium content of the samples, determined by scintillation alpha counting and fluorimetry, was compared with that of the other minor elements. Five elements—Fe, As, Co, Mo, Pb—showed a marked positive correlation with uranium.

PERMAFROST AND WATER SUPPLY OF POINT SPENCER SPIT, SEWARD PENINSULA, ALASKA

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Point Spencer spit separates Port Clarence and Bearing Sea, near the west end of Seward Peninsula, Alaska. The enlarged northern part of the spit, about 3 miles long and 1 mile wide, is joined to the mainland by a low sandy bar about 12 miles long. A prominent sand ridge 10–14 feet high parallels the west shore, and a lower ridge parallels the east shore of the enlarged part of the spit. Surficial quartz sand and limestone gravel about 35 feet thick overlie finer marine sediments. Most of the spit has stunted arctic vegetation. The climate is subarctic-marine.

The top of permafrost (ice-cemented sand and gravel) occurs 3 to 8+ feet from the surface and roughly parallels the surface; the base of permafrost is about 8 feet below sea level. Permafrost rises under the coastal ridges, producing a saucerlike, impervious layer that traps the only potable water on the spit. Excavation of borrow pits near the sea breached the rim of the layer, and sea water contaminated most of the potable water that had collected in and between borrow pits along the margins of the spit. In the central part of the spit water level rapidly rose 13–14 inches although no recharge was available. Damming of the outward-flowing fresh water by in-flowing salt water could account for only part of this rise; consequently ground water in the central part also may have been contaminated.

BIG SNOWY—AMSDEN STRATIGRAPHY IN SOUTHWESTERN MONTANA

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The stratigraphic equivalents of the Mississippian Big Snowy group thin considerably southwestward from the Big Snowy uplift in central Montana. The basal Kibbey red beds persist and

are believed to be derived in part from an upper Madison surface. The succeeding Otter and Heath formations composed essentially of shales with occasional thin limestone beds merge southwestward into a unit composed of dark carbonate rock with distinctive shaly partings. This unit thins and disappears locally within short distances apparently as a result of pre-Amsden erosion. Where this unit is absent the underlying Kibbey red beds merge with the overlying red beds of the basal Amsden to form a unit formerly considered to be Amsden in its entirety. In favorable exposures this demarcation between the Kibbey and Amsden formations can be identified in the sequence. This extends the known areal distribution of this part of the Big Snowy group.

COMPARISON OF AMINO ACIDS OBTAINED BY ACID HYDROLYSIS OF LAKE SEDIMENTS, CENTRAL MINNESOTA

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Hydrolyzates of various lake sediments, peat, and humic acid constituents of peat from central Minnesota were obtained by refluxing with 6 N hydrochloric acid for 22 hours. Separation of the hydrolyzates alongside known mixtures of amino acids on Whatman No. 1 sheets resulted in a remarkably similar distribution of amino acids from the natural sources; the concentrations, however, differ appreciably among the lakes and bogs.

The *Rf* values of the more distinctly separable spots correspond to those of aspartic acid, glutamic acid, glycine, serine, alanine, threonine, valine, and leucine and/or isoleucine. In these samples, the last three or four occur in relatively greater concentrations than the rest. Additional work is being done to learn whether this distribution of amino acids is related to existing environmental conditions, as contrasted to other types of environments.

CORRELATING THE GEOLOGY CURRICULUM WITH THE GENERAL-EDUCATION REQUIREMENTS OF THE COLLEGE

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The general-education requirements of colleges usually consist of basic courses in composition, literature, foreign language, history, mathematics, and social and physical science. In addition many church-related schools require courses in religion and often considerable work in related subjects.

It is imperative that the department of geology, in planning a curriculum for its majors, consider the general-education requirements as part of the geology program in order that both students and faculty members use the general-education courses to enrich the geology student's training. When some latitude is given in the selection of basic courses, the geology faculty should be prepared to advise majors in the best selection of courses.

In discussing general-course requirements the faculty must make the student conscious of the far-reaching value of these courses.

HYDROTHERMAL DOLOMITIZATION OF SANDSTONE, TEMPLE MOUNTAIN, UTAH

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Dolomitization occurred as an alteration prelude to uranium mineralization at Temple Mountain, Utah, on the east flank of the San Rafael Swell. It formed replacement masses in the Wingate sandstone (Moanave formation) which in one place measure hundreds of feet across. The emplacement

accompanied the formation of pipelike masses of downdropped strata described elsewhere as collapse features.

It is believed that the dolomite was deposited by upward-migrating solutions originating at depth which removed considerable quantities of calcite and dolomite from the Kaibab limestone and Moenkopi formation below and also caused argillic alteration. The removal was responsible for the formation of collapse features. The solutions, probably epithermal, underwent a gradual increase in pH upward, and in the higher strata dolomite was deposited and quartz removed.

The Wingate sandstone is a medium-grained quartzose sandstone with a kaolinite matrix containing minor amounts of detrital potash feldspar. The dolomite forms nodules engulfing and including the kaolinite rather than replacing it. Later stages involve the replacement of the quartz within the nodules accompanied by dolomitic cementation of the rock. At the end there is almost complete replacement of the sandstone. A final stage involves the deposition of dolomite, ankerite, and calcite in fractures and cavities. Al_2O_3/SiO_2, K_2O/SiO_2, and K_2O/Al_2O_3 ratios indicate that quartz is preferentially replaced before potash feldspar and kaolinite; kaolinite is the most resistant to replacement.

The occurrence is believed to illustrate dolomitization of detrital sediments by rising thermal solutions.

BREAKDOWN OF NEPHELINE UNDER PRESSURE

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A pressure-temperature diagram for the composition $NaAlSiO_4$ has been determined for the temperature range of 500° C to 850° C at pressures up to 40 kilobars. The "squeezer" type of apparatus was used. Under pressure, pure synthetic nepheline breaks down to two phases. The principal high-pressure phase, designated as N(1), is new; the less abundant high-pressure phase, designated as N(2), has optical properties which indicate a similarity to jadeite. The relative amounts of N(1) and N(2) in the breakdown products of nepheline are approximately 95% N(1) and 5% N(2).

The stable-phase assemblages encountered are pure nepheline, nepheline + N(2) and N(1) + N(2). The curve dividing the fields N(1) + N(2) and nepheline + N(2) passes through the points 630° − 10 kilobars, 685° − 15 kilobars, 730° − 20 kilobars, 765° − 25 kilobars, 790° − 30 kilobars, and 805° − 35 kilobars. The curve dividing the fields of pure nepheline and nepheline + N(2) is in the vicinity of 10 kilobars in the temperature region investigated. This latter curve could not be accurately located since it marks the appearance of an infinitesimal amount of N(2). Increasing the pressure in the field of nepheline + N(2) increases the relative amount of N(2). The curve dividing the fields of pure nepheline and phases N(1) + N(2) must lie at low temperatures in the pressure range below 10 kilobars. This curve has not yet been determined.

Runs have been made on a number of natural nephelines. The natural nephelines all reacted to nepheline + jadeitic pyroxene at pressures above 20 kilobars. The high-pressure phase N(1) has not been obtained using natural nepheline as a starting material.

COMANCHEAN STRATIGRAPHY OF KENT QUADRANGLE, TEXAS*

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Comanchean rocks in the 30′ Kent quadrangle, Trans-Pecos Texas, are classified, in descending order, into four formations: Buda limestone, a newly named limestone, Finlay limestone, and Cox

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sandstone. These formations are thinner than correlative units in the Sierra Blanca-Finlay Mountains region on the west and the Fort Stockton area on the east.

By means of a middle thick-bedded ledge of which the base is a suitable horizon for surface mapping, the newly named limestone may be subdivided into an upper limestone member, a middle limestone member, and an obscure basal shale member. In the subsurface, possibly four units will be recognized: the Buda combined with the two limestone members, the shale member, the Finlay, and the Cox.

Paleontologic zonation established in correlative areas is applicable to the Kent area as follows:
Buda limestone: *Budaiceras* spp., *Pecten* (*Neithea*) *roemeri*, and *Nerinea volana*
Upper limestone member: *Turrilites brazoense*, *Ostrea quadriplicata*, and *Mortoniceras wintoni*
Upper part of lower limestone member: *Leonites* spp.
Lower part of lower limestone member: *Mortoniceras trinodosum*
Lower part of shale member: *Desmoceras brazoensis*, *Elobiceras* sp., and *Gryphaea navia*
Finlay limestone: *Oxytropidoceras* aff. *O. belknapi*, *Toucasia* sp., *Pecten* (*Neithea*) *duplicicosta*, and *Ostrea crenulimargo*

GEOCHEMICAL STUDIES OF COALIFIED WOOD FROM THE COLORADO PLATEAU COAL

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Chemical and petrographic studies of coalified logs from Triassic and Jurassic sediments of the Colorado Plateau revealed modes of formation of opaque matter not previously reported. The petrographic examination was made by means of polished, thin, and polished-thin sections of the material. In all samples examined an inverse relationship exists between opaque or poorly translucent organic matter and volatile content.

Ten of the 33 samples examined were available in sufficient quantity for standard Bureau of Mines coal analyses. On the basis of these analyses, the coalified wood was classified as subbituminous B to medium volatile bituminous in rank. Although most samples contain 65–84 per cent carbon, no sample yet found contains more than 84 per cent carbon. Hydrogen values range from 3.3 to 7.5 per cent; organic sulfur in a number of samples is very high (maximum 13.1 per cent). Coalification is extremely variable as indicated by a wide range of carbon and hydrogen values for specimens from a single small sample or for samples from a single locality. Both petrographic and chemical evidence indicates that mode of preservation, rather than metamorphism, is primarily responsible for the wide range of most analytical values.

LATE WISCONSIN HISTORY OF LAKE LAHONTON

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The late Wisconsin lake-level history of pluvial Lake Lahonton has been reconstructed by radiocarbon measurements on tufa and shell samples from the Pyramid Lake area. Measurements show that moderna tufa contains an equilibrium amount of C^{14}, hence ages obtain on fossil tufa should be reliable.

Measurements indicate that nearly all the tufa found in the Lahonton area has formed during the past 30,000 years.

Deposits associated with wave-cut caves suggest a fairly uniform lake level between 250 and 300 feet above the present level of Pyramid Lake from 17,700 to 13,000 years B.P. A low level at 12,500 years was followed by the maximum Lahonton level at 11,700 years B.P. as indicated by tufa samples

from the highest terraces. Dry cave deposits dated at 11,200 show that this maximum was followed by a rapid desiccation.

Ages on tufa samples obtained from the lake sediments exposed in the gorge cut by the Truckee River enable a correlation to be made with the cave and terrace deposits. The upper clay member records two high-water levels, one before 17,700 and one after 12,900.

Because of the dependence of the level on temperature and rainfall the fairly rapid large fluctuations in Lake Lahonton suggest rather sudden climatic changes at the close of the Wisconsin. The rapid desiccation of the lake subsequent to its 11,700 year maximum correlates perfectly with the sharp climatic change recorded in Atlantic Ocean cores and is thought to mark the end of the Wisconsin.

IDENTIFICATION OF CORDAITEAN POLLEN AND STRATIGRAPHIC IMPLICATIONS

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Fossil spores and pollen are used extensively for correlating coal seams. Such plant microfossils detached from their parent plants, are commonly classed into form genera and species for purposes of identification. A study of the descriptions of form genera and species indicates that the characteristics differentiating them are sometimes vague and often allow for duplications of described forms. Different orientations of a specimen can be problematic in correctly identifying a plant microfossil. It is therefore suggested that, in studying isolated fossil pollen from sediments, temporary mounts of glycerin as well as more premanent mounts be prepared. Temporary mounts are useful for studying various orientations of individual specimens. The permanent slides can be utilized for the storage of type specimens and statistical counts.

Pollen from four species of *Cordaianthus* were studied in an attempt to evaluate standard palynological techniques. The pollen grains of *Cordaianthus* are surrounded by a bladder and possess on their proximal side a triradiate scar, which is not evident from the distal view. A striking similarity exists between the proximal aspect of cordaitean pollen and the form genus *Endosporites*, whereas the distal aspect of the same pollen grain is like the genus *Florinites*. Moreover, intermediate orientations appear similar to published descriptions of form species of these two genera. Consequently, although the pollen of *Cordaianthus* may be represented by several form species and genera, the species of this cone cannot be distinguished on the basis of differences in pollen.

EFFECT OF BEDROCK ON CHARACTERISTICS OF HEADWATER STREAMS IN CENTRAL PENNSYLVANIA*

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Several hydraulic factors were studied to determine the effect of three types of bedrock (sandstone, shale, limestone-dolomite) on characteristics of headwater streams in central Pennsylvania. The parameters selected for study were channel slope, particle size of the bed material, and the length of stream (distance from headwater divide). Forty-nine sampling stations on 16 streams were investigated, and data for the hydraulic parameters were grouped according to lithology. Regression, variance, and covariance analyses show that channel slope is inversely proportional to length of stream for each lithology, but the equations expressing this relationship are significantly different for the various types of bedrock. For similar types of bedrock, particle size does not change significantly downstream. However, for a given length of stream, particle size is significantly different

* Publications approved by Director, U. S. Geological Survey

for each type of bedrock. Streams flowing on sandstone have larger particles than streams flowing on shale, which, in turn, have larger particles than streams flowing on limestone-dolomite. For similar types of bedrock, slope and particle size are not significantly correlated. However, in some of the individual streams which flow over different types of bedrock, a decrease in slope in a downstream direction is accompanied by a decrease in particle size. This relationship does not appear to reflect cause and effect but is an expression of local characteristics of weathering, jointing, and resistance to erosion of the bedrock.

CRYSTAL STRUCTURE OF PECTOLITE AND WOLLASTONITE

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Pectolite, $Ca_2NaHSi_3O_9$, and wollastonite, $CaSiO_3$, are members of the same triclinic family, with symmetry $P\bar{1}$. Pectolite has $a = 7.99$A, $b = 7.04$, $c = 7.02$, $\alpha = 90°03'$ $\beta = 95°17'$, $\gamma = 102°28'$. Wollastonite has approximately the same cell except that $b = 7.32$A.

The structures of these crystals were determined by solving with minimum-function methods the several Patterson projections, followed by Fourier refinement. The structures are characterized by chains of silica tetrahedra parallel to b. These chains have a different shape from the silica chains found in the pyroxenes. The Ca atoms can be crudely described as forming sheets of octahedra parallel to (101), except that these sheets display peculiar rifts parallel to b.

GYPSIFICATION VIA TRANSIENT DOUBLE SALTS*

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Petrographic studies show that many gypsum deposits have been formed by the hydration of anhydrite, but the mechanism for hydration has never been fully explained. Gypsum has been produced experimentally by agitation of anhydrite in pure water, a reaction that is accelerated by certain acids, bases, and salts.

Present investigations show that the following ions in order of decreasing effectiveness activate this hydration:

$$K^+ \geqq Na^+ \geqq NH_4^+ > Mg^{++} > Fe^{++} > H^+ > Al^{+++} > Ca^{++}$$
$$SO^{=} > Cl^- > OH^-$$

The abundance of many of these ions in subsurface waters indicates that such an activation process may play a significant role in nature. In general, rate of conversion varies inversely with grain size. Experiments between 0° and 45°C. indicate that conversion ceases at about 42° which is the gypsum-anhydrite-water equilibrium temperature.

Activator cations in natural waters initiate conversion by transient double-salt formation. Subsequent decomposition of the double salt results in precipitation of less soluble $CaSO_4 \cdot 2H_2O$.

Contrary to recent hypotheses of gypsum dehydration by concentrated solutions, double salts and/or gypsum are stable phases below a temperature of about 42°C. Above 42°C. double salts may replace anhydrite as the stable phase. Gypsum, however, may remain a metastable phase indefinitely in its saturated solution below the hemihydrate transition temperature (98°C.).

This mechanism also implies that the abundance of cation activators present in sea water causes the primary precipitation of gypsum below 42°C. even in many concentrated solutions.

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MINERALOGIC VARIABILITY IN GLAUCONITELIKE PELLETS AND ITS APPLICATION IN STRATIGRAPHIC STUDIES

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Approximately 200 specimens of green pelletal materials of various geologic ages have been examined by *x*-ray diffraction in an attempt to reconcile the many diversified forms of "glauconite" with the mineral glauconite as it has been classically established. Valuable mineralogical information available within certain argillaceous pellet forms is being overlooked by the misappropriation of a mineral name as a morphological description.

Materials classified by field examinations as glauconite seldom reflect the well-organized micaceous structures found in the Cretaceous greensands of New Jersey or the Cambrian glauconites of Wisconsin and Missouri. This is particularly true for Tertiary materials of the Texas Gulf Coast area. Most commonly present in field-run "glauconite" are the interlayered clay materials illite-montmorillonite and illite-chlorite. Also noted are pellets containing various combinations of illite, chlorite, montmorillonite, and kaolinite. Some of these combinations are specific enough to characterize the chemical analysis, and it is thought that variabilities in the glauconite chemical formula might be restricted by careful *x*-ray monitoring.

Classification to these frequently occurring pellets on the basis of mineralogy provides a useful basis for stratigraphic correlation.

VANADIUM-URANIUM DEPOSITS IN THE ENTRADA SANDSTONE, WESTERN SAN JUAN MOUNTAINS, COLORADO

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Vanadium deposits in the Placerville, Rico, and Lightner Creek districts of Colorado contain enough uranium to be of by-product value. The deposits are mineralized sandstone layers in the upper part of the Entrada sandstone (Jurassic). Generally the ore layers parallel bedding but do not conform to bedding in detail. Roscoelite, the principal ore mineral, fills spaces between sand grains and coats the grains. Carnotite is the only uranium mineral identified in the deposits.

Ore layers range in thickness from a knife edge to more than 20 feet. Ore bodies within the ore layer range from a few tens of feet to several hundred feet across and contain from a few tons to many thousand tons of ore.

In the Placerville district deposits form an essentially continuous elongate layer more than 9 miles long and 1½ miles wide, trending slightly west of north. Deposits in the Rico and Lightner Creek districts have similar habits and are interpreted as belts of similar trend and dimensions. The present outcrop pattern suggests three belts, en echelon along a south-trending line, but the belts may be parts of a single continuous sinuous belt. Deposits seem genetically unrelated to Tertiary dikes, sills, and faults which cut them.

The average thickness of ore layers, and the number and size of ore bodies, decreases southward. The total amount of ore in the layer at Placerville probably is several times that at Rico, and many times that at Lightner Creek.

OCCURRENCE OF CHROMITE DEPOSITS IN THE EASTERN PART OF THE BUSHVELD COMPLEX

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Field investigations during 1951–1955 have clarified the "stratigraphy" of the Critical Zone in the eastern Bushveld Complex and the occurrence of chromite deposits. The Critical Zone comprises

a lower pyroxenite series, predominantly pyroxenite and mafic norite, and an upper anorthosite series, predominantly anorthosite and anorthositic norite. In sections measured, the pyroxenite series is 1900–2200 feet thick, the anorthosite series 2500–3500 feet thick.

Three principal groups of chromite seams are recognized. The Lower Group, in the lower half of the pyroxenite series, is exposed northward from Steelpoort. Seams of this group, including the highly productive Steelpoort seam, are concordant with pseudostratification, persistent for long distances, and relatively constant in thickness and grade. The Middle Group occurs in the upper 100 feet of the pyroxenite series. Southward from Steelpoort it includes three major seams. The upper and lower, in pyroxenite, are structurally and lithologically similar to seams of the Lower Group. The middle seam, associated with anorthosite, is highly variable in thickness and has numerous partings. The Upper Group comprises seams from 400 feet above the anorthosite-pyroxenite contact to the Merensky Reef. Seams of this group, best known from Dwars Rivier, are concordant to fracture-controlled and locally show penecontemporaneous deformation. Single seams are mostly nonpersistent and variable in thickness, but the group extends at least 60 miles along strike.

The new grouping of chromite seams requires a restudy of variations in composition of chromite with "stratigraphic" position in the Critical Zone. The variation is apparently less simple than heretofore supposed.

NEW ALBANY SHALE AND KINDERHOOK SERIES IN INDIANA

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A complete sequence of the New Albany shale and the Kinderhook Series occurs in Clark County as follows: Blocher and Blackiston black shales, (Devonian); Sanderson black shale, Underwood gray shale, Henryville black shale, Jacobs Chapel gray shale with 60 species, a nonfossiliferous Ferruginous limestone, typical Rockford limestone, and an overlying gray shale with 60 species (Mississippian). Each division, except the Ferruginous limestone, contains a characteristic fauna.

The type Rockford overlaps unconformably the Ferruginous limestone, erroneously identified as Rockford, south to central Clark County; the Ferruginous limestone extends to the Ohio River but does not occur in outcrop in Kentucky. A subsurface limestone occurs at the Kinderhook level in the Kentucky counties bordering the Ohio River southwest to Illinois.

The Sanderson with characteristic fossil plants extends across Kentucky and occurs beneath the Bedford in Estill County. Compared with the Illinois sequence on fossil evidence the lower Blackiston correlates with the Grassy Creek, the Underwood with the Glen Park, and the type Rockford and overlying shale with the Chouteau. The beds, Sanderson through the Ferruginous limestone, are Hannibal in age.

The Cincinnati arch was not a landmass during New Albany time, and the use of the geographical position of that positive area as a boundary for the stratigraphy of the Central Interior region gives a false impression of the physiography of the New Albany-Kinderhook interval.

DISCONFORMITY BETWEEN LOWER AND UPPER CRETACEOUS IN WESTERN COLORADO AND EASTERN UTAH

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In a part of western Colorado and eastern Utah the contact between the Burro Canyon formation (Lower Cretaceous) and the Dakota sandstone (Upper Cretaceous) is a broadly undulating erosional surface. Angular and subangular pebbles, cobbles, and boulders of sandstone, chert, and quartzite derived from the Burro Canyon have been found in the basal part of the Dakota sandstone. The presence of these fragments and a thin quartzite bed at the top of the Burro Canyon indicate that the formation was lithified, probably under subaerial conditions, prior to its erosion and deposition

of Dakota sandstone. On the basis of fossil plants R. W. Brown (1950) placed the boundary between the Lower and Upper Cretaceous at the top of the Burro Canyon. The field evidence described here supports this division and further suggests a hiatus between the Lower and Upper Cretaceous sediments in part of the Colorado Plateau.

CRYSTAL STRUCTURE OF MEYERHOFFERITE, $2CaO \cdot 3B_2O_3 \cdot 7H_2O$

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Meyerhofferite is triclinic $P\bar{1}$, $a = 6.63$, $b = 8.35$, $c = 6.46$ A (all $\pm$ 0.015 A), $\alpha = 90°46'$, $\beta = 101°59'$, $\gamma = 86°55'$ (all $\pm$ 05'); Z = 1 [$2CaO \cdot 3B_2O_3 \cdot 7H_2O$], density (calc.) = 2.125, density (obs.) = 2.120. The structure was determined from electron-density projections normal to the three crystallographic axes, calculated using phases determined by the direct statistical method of Hauptman and Karle.

The crystal contains polyions consisting of two $BO_2(OH)_2$ tetrahedra, and a $BO_2(OH)$ triangle, linked to form a ring of composition $[B_3O_3(OH)_5]^{-2}$. The average B–O distance in the tetrahedra is 1.49 A and in the triangle, 1.38 A. Each Ca^{++} is co-ordinated by 6 oxygens and 1 H_2O at an average distance of 2.40 A. The structural formula for meyerhofferite is $CaB_3O_3(OH)_5 \cdot H_2O$. The isolated groups in meyerhofferite are the same elements which condense to form the infinite chains of colemanite:

$$n[B_3O_3(OH)_5]^{-2} = [B_3O_4(OH)_3]_n^{-2n} + nH_2O.$$

Reliability factors for the initial structure are: hO1, 0.19; hkO, 0.19; Ok1, 0.21.

At the present stage of refinement the atomic parameters are:

Atom	*x*	*y*	*z*
Ca	0.010	0.377	0.243
O_1	.407	.734	.327
O_2	.422	.889	.651
O_3	.115	.776	.502
O_4	.339	.461	.211
O_5	.058	.642	.145
O_6	.165	.374	.615
O_7 (H_2O)	.132	.104	.211
O_8	.145	.126	.797
O_9	.334	.673	.955
B_1	.318	.792	.497
B_2	.308	.642	.183
B_3	.030	.278	.683

AMMONIOBORITE AND LARDERELLITE

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Ammonioborite, proposed by Schaller in 1933 as a new mineral species and probably a dimorph of larderellite, has been re-examined by *x*-ray methods. *X*-ray powder patterns of synthetic ammonioborite and larderellite from Larderello, Italy, are distinctly different. Single crystals of synthetic ammonioborite yield the following *x*-ray data: Monoclinic, a = 25.2_7, b = 9.65_1, c = 11.5_8 A (all $\pm$ 0.015 A), $\beta = 94°17' \pm 05'$; space group *Cc* or *C2/c*. Although the *x*-ray data indicate no departure

from monoclinic symmetry, optical examination shows that ammonioborite is triclinic. The morphology of the crystals indicates no departure from holohedral symmetry, nor could the lack of a center of symmetry be demonstrated by piezoelectric tests. The true space group is therefore probably $P\bar{1}$.

The observed density of ammonioborite is 1.76$_7$. For the formula proposed by Schaller, *i.e.* $(NH_4)_2O \cdot 5B_2O_3 \cdot 5H_2O$, and Z = 6, $d_{(calc.)} = 1.737$, a significantly discrepant value. For the ratio of oxides 1:5:5½, $d_{(calc.)} = 1.769$; for 1:5:5⅓, $d_{(calc.)} = 1.758$. The $P\bar{1}$ symmetry would favor the 1:5:5⅓ formula, which moreover affords the best agreement with recent unpublished chemical analyses made by Schaller. The most probable formula for ammonioborite is therefore $3(NH_4)_2O \cdot 15B_2O_3 \cdot 16H_2O$.

Single crystals of larderellite are not available. On the basis of all the available evidence it is not known whether ammonioborite and larderellite are dimorphous, although it is clear that they are distinct mineral species.

RADIATIVE TRANSFER AND THE TEMPERATURE IN THE MANTLE

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The effective thermal conductivity of a nonopaque substance is to a first approximation given by

$$C = K + \frac{16n^2\sigma T^3}{3\epsilon} \qquad (1)$$

where K is the ordinary thermal conductivity, σ is the Stefan-Boltzmann constant, n is the index of refraction, T is the absolute temperature, and ϵ is the "opacity" of the substance. The second term in this expression takes account of heat transfer by radiation. A more detailed examination of the problem shows that this simple expression gives a far better approximation to the effective conductivity of silicates than one might expect.

The opacity, ϵ, is a function of pressure and temperature; its pressure coefficient is likely to be small, and its variation with temperature is linear over the range for which data are available. Uncertainties in the pressure and temperature coefficients of ϵ in the earth are small compared with the uncertainties introduced by lack of knowledge of the composition of the mantle.

Since the second term in (1) increases with temperature, high effective conductivities are expected at high temperatures. The effective conductivity deep in the mantle is likely to lie between 0.01 and 0.03 cal./cm.sec.°C. As a consequence, considerable amounts of heat may be conducted from deep in the earth with relatively small temperature gradients. Radiative transfer may set an upper limit to the temperatures possible in the earth.

RUBIDIUM-STRONTIUM AGE DETERMINATIONS ON THE MINERAL GLAUCONITE

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Several glauconites from sedimentary strata which are well dated by index fossils have been studied. The concentrations of rubidium, normal strontium, and radiogenic strontium have been determined mass-spectrometrically using the stable isotope dilution method of analysis. The glauconites thus far analyzed represent material from strata of Eocene, Cretaceous, Ordovician, and Cambrian ages. Absolute ages of the samples analyzed have been computed using a half-life for the 87 Rb decay of 50×10^9 years. Results of the analyses are shown in Table 1. The results of analyses

of several other glauconites now in progress will also be reported. Standard deviations of the ages given range from 6–8% for the Cambrian samples to 15% for the Cretaceous samples.

TABLE 1

Index fossil Age	Locality	Rb ppm	Normal Sr	Radiogenic Sr ppm	Age in 10^6 yr units $\lambda = 1.39 \times 10^{-11}$ yr^{-1}
Lower Eocene	Clayton, N. J. Hornerstown fm.	238	10.3	.056	60
Upper Cretaceous	Clayton, N. J. Navesink fm.	220	17.0	.061	70
Upper Cretaceous	N. J.	259	11.6	.063	62
Lower Ordovician	Stenbrottet, Sweden	311	12.8	.46	375
Lower Ordovician	Stenbrottet, Sweden	307	16.7	.46	381
Upper Cambrian	Central Texas Riley fm.	229	40.8	.36	401
Upper Cambrian	Central Texas Riley fm.	203	43.0	.33	413
L. Middle Cambrian	Alberta Mt. Whyte fm.	186	116	.34	470

CORRELATION OF THE POMEROY COAL

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Identification of Pomeroy coal in the vicinity of Mason County, West Virginia, and adjacent areas in Ohio has long been controversial. Recent studies here and farther south and west in West Virginia and Ohio show two coals, Pittsburgh and Redstone, present. Either may be well developed locally. Either or both may be thin or absent. Certain lithologic and other stratigraphic features of these coals or their associated strata were used to distinguish them. Later microfossil studies have corroborated most of these determinations.

Where Pittsburgh coal is mined, it may be overlain by limy shales, fresh-water limestones and siltstones, or in places by massive sandstone. Where Redstone coal is mined as Pomeroy, it is usually overlain by massive sandstone, and the position of Pittsburgh may be indicated by thin coal or carbonaceous shale about 25 feet below in a limestone-shale sequence.

Plant microfossil assemblages of both Pittsburgh and Redstone (Pomeroy) coals are dominated by *Laevigato-sporites* spores. Detailed statistical studies of bench and interval samples were undertaken. Spores represented in both coals are essentially the same, but there is consistent variation in their relative abundance. The species *Laevigato-sporites thiessenii* is abundant in Pittsburgh and rare in Redstone (Pomeroy). Species of *Endosporites*, *Punctati-sporites*, and *Calamospora* are more abundant in Redstone than Pittsburgh.

Both Pittsburgh and Redstone seams are present in portions of this area, and identification must be made on each seam locally. The principal seam mined in the Mason County field is equivalent to Redstone.

SYSTEM Mg_2SiO_4—Mg_2GeO_4 AT 10,000, 60,000, AND ABOUT 300,000 PSI

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The olivine-spinel transition in forsterite which has been postulated as a mechanism for explaining certain seismic discontinuities has been studied hydrothermally in the system Mg_2SiO_4—Mg_2GeO_4.

The transition in Mg_2GeO_4 takes place at 825°C at 10,000 psi and is raised by 20°C per 1000 atmospheres. An isobaric t-x section for the system has been worked out at 10,000 psi. A maximum of only 7% of SiO_2 enters the spinel phase at this pressure (at 580°C). Portions of the system have also been studied at 4000 atmospheres showing an increase in solid solubility of Mg_2SiO_4 in "spinel" of 2½%. Another isobaric section has been made in "directed-pressure" apparatus at a pressure estimated at 20,000 atmospheres. Using x-ray cell-size measurements the limits of homogeneous olivine and spinel solid solutions have been estimated; at this pressure single spinel phases containing about 18% Mg_2SiO_4 can be prepared. Extrapolation in the p-t-x cube suggests some limits on pressures and temperatures required for this inversion in natural olivines.

FURTHER INVESTIGATIONS OF EXCESS HELIUM AND ARGON IN MINERALS AND ROCKS

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Results of earlier work in this laboratory have shown that the excess of He^4 in beryl is always accompanied by excess A^{40} but without detectable A^{36} or neon. A similar excess of inert gases was noted in the structurally similar mineral, cordierite. The inert gases are quantitatively released from these minerals at the "Zerfalls" (Böse) temperature (900–1100°C), but fusion (1450°C) is required to release completely the remaining volatile constituents. Trace quantities of nonvolatile elements are also released at the "Zerfalls" temperature and can be collected as a sublimate on glass wool in cooler parts of the furnace system. These results show that the gas has been occluded by the mineral rather than being the product of nuclear processes within the mineral. Further attention has been given to the $He^4 = A^{40}$ ratio in this occluded gas which is higher than the ratio of the production rate of helium to argon in igneous rocks or average shale. The higher ratio could be the result of preferential occlusion of helium over argon by the minerals or more likely by preferential mobilization of helium over argon during the partial fusion of a metamorphic terrain. The latter mechanism is supported by the lower retentivities of various minerals for helium and by the observation of the highest ratio for the gases from the metamorphic mineral cordierite. Investigation of feldspars and micas including albite and margarite has shown no evidence for an excess of helium or argon in these minerals.

PETROLEUM INDUSTRY LOOKS AT THE GEOLOGY CURRICULUM

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The geology curriculum for petroleum work should ideally reach the master's-degree level or beyond. Students of exceptional maturity and experience may not require so much formal education, but student achievement must be individually judged in the light of preparation for life-time careers and future development—not simply as to their readiness to "get a job." Appreciation of the curriculum's importance as a foundation for future professional growth cautions against too great an investment of the student's time and learning in specialized techniques and skills. Emphasis should be on the thorough understanding of principles of geology and supporting sciences, the development of high standards of achievement, and the ability to communicate effectively in speech and writing. A desirable curriculum for the student contemplating employment in the field of petroleum is presented.

Individual and frequent counseling of students is thought to be of prime importance. Each student

should be encouraged to learn early and at first hand what it is that geologists actually do. In combination these will work toward the self knowledge essential to wise curricula planning and the solid motivation so necessary for high academic achievement.

GRADES OF DIAGENESIS IN SANDSTONES

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Varieties of sandstones ranging from complex mineral assemblages in graywackes and arkose to simple associations in quartzose groups reveal facies of diagenetic stages preceding development of metamorphic grades. These are responses to pressure, temperature, and active solution transfer to which the original sediment is subjected. Increments of pressure are measured by degree of intersuturing between adjacent quartz grains. Temperatures range into those of low-grade metamorphism. Solutions are believed to be connate waters squeezed from shales during compaction and are considered high in alkalis and lime, and of high pH. Information permits establishment of three grades of diagenesis:

Low grades are recognized by (1) absence of reaction between adjacent mineral species; (2) quartz overgrowths; (3) secondary chert (minor); (4) replacement of quartz by calcite (minor).

Intermediate grades are indicated by (1) clearly defined intersuturing of quartz; (2) strong replacement of quartz by calcite; (3) glauconite forming from illite matrix; (4) glauconite being replaced by calcite; (5) calcite replacing feldspar; (6) illite altering to muscovite and biotite; (7) strong addition of secondary chert; (8) development of large plates of white mica.

High grades of diagenesis are recognized by (1) alteration of glauconite to chlorite; (2) strong development of white mica, derived from matrix and penetrating feldspars; (3) alteration of finely divided mixture of quartz, illite, or montmorillonite to chlorite; (4) appearance of secondary epidote; (5) interstitial intergrowths of chert, sericite, and chlorite.

Intergradation between high-grade diagenesis and low-grade metamorphism is suggested but not yet substantiated.

FOUNDATION PROBLEMS IN THE ST. PETER SANDSTONE, ST. ANTHONY FALLS LOWER LOCK AND DAM, MINNESOTA

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The Lower Lock and Dam at St. Anthony Falls, Minneapolis, Minnesota, is a part of the overall project for the extension of the 9-foot channel a distance of 4.6 miles above the existing head of navigation on the Mississippi River. The soft, weakly cemented, friable St. Peter sandstone which provides the foundation for the structures required a lock structure of the dry-dock type with integral bottom slab and walls. To complete the design of the lock the foundation modulus had to be determined by bearing tests on different-sized plates. A number of problems were encountered as construction progressed, most of which were due to the characteristics of the St. Peter sandstone. The sandstone was found to have uncemented seams in horizontal layers every 3 to 5 feet vertically which would blow out when open sump methods were tried for dewatering. Deep sheet pile cut-off walls were installed as part of cofferdam construction to shut off flow through seams which had blown and created open fissures. Pilings could not be driven directly into the sandstone but were placed in trenches which were cut in the sandstone with high-pressure water jets. Chemical solidification of the

disturbed sandstone in the trenches which extended through the structure was required. Well points were used successfully for predraining areas where a deep cut-off key extended along the upstream face of the dam.

PROFESSIONAL ETHICS AND CONDUCT FOR ECONOMIC GEOLOGISTS

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Vast expansion in the field of Economic Geology since World War II, especially in connection with the recent uranium boom, warrants a current appraisal of professional ethics and conduct. Logical categories for review are interprofessional, employer, and public relationships.

Interprofessionally the consulting geologist is well advised to practice the Golden Rule.

With his employer, the geologist's chief duty is loyalty. Honesty and integrity go without saying. Compensation other than on a fixed fee basis is questioned. Contingent interests tend to color judgment but perhaps are allowable under certain conditions and where made public knowledge.

Concerning the public, modern professional duty transcends mere factual reporting on mineral reserves. An opinion is required, additionally, as to the economic potentialities of these occurrences. As an expert witness, the geologist should testify only when he believes in the rightness of his client's case. Professional fees justifiably vary. Individuals with low overhead may charge less than consulting firms with necessarily high overhead, and rates may vary among countries depending on currency status.

Dignified advertising of services involving large capital investment (aerial investigations) is considered proper and desirable as it stimulates competition and efficiency in a free enterprise system.

A spelled-out ethical code for economic geologists appears undesirable. Professional individuals and groups should adopt a credo above reproach, thereafter in Polonius' words "to thine own self be true, and it must follow as the night the day, thou canst not then be false to any man."

RAINY DAY URANIUM DEPOSIT, GARFIELD COUNTY, UTAH*

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The Rainy Day mine is a unique uranium deposit in the Circle Cliffs area, Utah. Ore is localized in siltstone of the Moenkopi formation (Triassic), on the southeast edge of a paleochannel 4000 feet wide by 40 feet deep, that is filled with sandstone of the Shinarump member of the Chinle formation of Triassic age. Shales of the Chinle rest directly on siltstone of the Moenkopi on either side of the channel. The pod of ore is of moderately high grade, measures 1 by 3 feet in cross section, and is continuous for a mined distance of more than 1100 feet. Sphalerite, chalcopyrite, pyrite, marcasite and galena are associated with a black uranium mineral, probably uraninite. Semiquantitative spectrographic analyses show that lead, copper, nickel, cobalt, silver, molybdenum, zinc, yttrium, and ytterbium increase proportionately with the uranium content. The relative increases of copper, nickel, cobalt, and lead, and ytterbium and yttrium are very similar, suggesting that the metals in these two groups are very closely related.

The deposit is on the east flank of the northwest-trending Circle Cliffs anticline. In detail, it occurs at the intersection of a 5-mile-wide anticlinal nose, trending transverse to the east flank of the Circle Cliffs anticline, and the inflexion point of a structural bench trending parallel to the anticline. The intersection of these smaller structures produces a domelike structure superimposed on the flank of the larger anticline. These structures may have facilitated deposition of ore in this locality.

* Approved by Director of the U. S. Geological Survey.

TROPICAL VEGETATION PEATS AND COAL FORMATION

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Mangrove swamp peat, Everglades saw grass marsh peat, and some other peats of Florida are extensive and occur in deposits up to 15 feet in depth. The "coal analysis reports" of profiles show definite carbonization in the ratios of H, C, N, and O for analyses of 200 samples from 25 sites. Carbon-14 determinations show ages up to 5000 years for deep layers. The herbaceous, fibrous parts indicate the exact vegetation from which each layer was formed. The tropical and subtropical nature of most of this vegetation is definite and significant.

These facts indicate that peat from tropical vegetation shows definite carbonization toward coal formation. Some profiles in the coast mangrove swamps indicate that peat of coastal littoral areas in the tropics may have formed coal. This marine conversion of peat to coal is significant.

Cores up to 45 feet in depth from the Oklawaha Valley show alternate deposits of fresh-water and salt-water peat related to levels of glacial and interglacial sea stages. The lower peats of these cores are carbonized almost to lignite, and some were probably formed from mangrove swamp or salt marsh vegetation. The interbedded layers of sand, clay, and marine peat and marl may constitute a series of deposits similar to a cyclothem of coal beds.

GRINDING HARDNESS OF DIAMOND IN A PRINCIPAL CUTTING DIRECTION

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A series of facets in zone [010] was ground on a diamond. The grinding direction was maintained parallel to the zone axis, and the cutting rates were determined. The grinding hardness of diamond even along a principal (four-fold) axis is dependent upon the orientation of the surface on which the measurement is made.

It is not possible to represent a grinding hardness solid, analogous, for example, with the optical indicatrix of transparent crystals. The implication is that, if it were possible to develop a theory of grinding hardness in diamond, the simplest hardness model must be represented by a tensor of at least fourth order.

CONCENTRATION OF MINOR ELEMENTS IN CARBONACEOUS FRACTIONS MECHANICALLY SEGREGATED FROM SOME SEDIMENTARY ROCKS

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Certain elements are concentrated in organic fractions separated from sedimentary rocks; their enrichment factors in the organic matter as compared to the mineral matter are shown in Table 1. Except for carbon and uranium, these data were derived from semiquantitative spectrographic analyses of the ash of organic and mineral separates and of original rock; the analyses were converted from ash basis to original basis for comparisons.

Except for uranium, lanthanum, and cerium, none of the elements concentrated in the organic matter is dominantly lithophile. V, Fe, Co, Ni, Cu, Zn, Mo, Ag, Pb, and Sn characteristically form complex compounds which might be fixed with the organic material. The mineral fractions show the expected concentrations of Si, Al, Ca, Mg, Na, K, Ba, Sr, Ti, and Zr. Elements not significantly concentrated in either fraction are Be, Sc, Cr, Ga, Mn, Y, and Yb. Neither Bi (limit of detection 50 ppm) nor Ge (limit of detection 10 ppm) was found in any fraction.

TABLE 1

	C	B	P	V	Fe	Co	Ni	Cu	Zn	As	Mo	Ag	Sn	Pb	U	La	Ce
Sharon Springs member, Pierre shale; Late Cretaceous	6	2	..	..	..	..	..	..	..	>5	..	..	..	..	..	..	..
Shale from Dakota formation; Cretaceous	60	..	..	..	..	..	..	10	..	..	..	..	2	10	100	>2	2
Argillite from Lockatong formation; Late Triassic	27+	10	5	..	..	..	..	100+	..	..	>2	20+	>100	>10	..	..	..
Shale from Phosphoric formation; Permian	18	2	..	10	20	2	10	20+	10	..	2+	50+	..	10	..	2	..
Chattanooga shale; Devonian	5–10	2	..	2	2	..	..	..	..	..	..	..	..	..	..	..	..
Dripping Springs quartzite; Precambrian	62	2	..	..	..	..	..	10	..	..	10	2+	10	2	..	..	..

EFFECT OF SOME STRONG-WEAK CATION ASSOCIATIONS ON THE DISTRIBUTION OF Mg AND Fe^{2+} IN COEXISTING MINERALS

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Although orthopyroxene contains twice as many six-co-ordinated positions as Ca-pyroxene, Ca-pyroxene contains more Ti, Fe^{3+}, and six-co-ordinated Al than the coexisting orthopyroxene. For Ca-pyroxene, the amounts of Ti, Fe^{3+}, and six-co-ordinated Al are strongly correlated only with the Ca deficiency of the mineral. Accordingly, Ti, Fe^{3+}, and six-co-ordinated Al largely occupy Ca positions rather than regular six-co-ordinated positions in Ca-pyroxene.

The higher $Mg/Mg+Fe^{2+}$ ratio of Ca-pyroxene than of coexisting orthopyroxene is also opposite to the predicted fractionation. If it is assumed that Fe^{3+} avoids positions which share some anions with Ti, Fe^{3+}, and six-co-ordinated Al, these positions are essentially Mg positions. If the Mg content of the mineral is reduced by this amount and the remaining Mg used to calculate the $Mg/Mg+Fe^{2+}$ ratios, Mg—Fe^{2+} distributions in nearly equivalent positions in the minerals can be compared. After such recalculations, Ca-pyroxene has, in general, a significantly lower $Mg/Mg+Fe^{2+}$ ratio.

Hornblende has a higher $Mg/Mg+Fe^{2+}$ ratio than coexisting orthopyroxene, a lower ratio than coexisting Ca-pyroxene, and contains more Ti, Fe^{3+}, and six-co-ordinated Al than either pyroxene. The above Mg correction results in a lower $Mg/Mg+Fe^{2+}$ ratio for hornblende than coexisting pyroxenes. The Ti, Fe^{3+}, and six-co-ordinated Al contents in hornblende are strongly correlated with the $Mg+Fe^{2+}$ deficiency and Na content.

The influence of the strong—weak (Ti, Fe^{3+}, Al—Ca, Na) cation association reverses the predicted overall Mg—Fe^{2+} fractionation in these minerals. Similar relationships in other minerals and crystal growth implications are discussed.

REGIONAL GRAVITY SURVEY IN VERMONT, WESTERN MASSACHUSETTS, AND EASTERN NEW YORK

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During 1950 and 1951, about 1200 gravity stations, spaced at intervals of about 4 miles, were established between 72° and 74° West and 42° 15′ and 45° North.

The main gravity trends are northerly and exhibit a marked parallelism with the major tectonic trends. Two major gravity features are present: a prominent gravity low over the Lake Champlain-Hudson Valley synclinorium (minimum Bouguer value −75 milligals 15 miles east of Albany) and a marked gravity high over the adjacent Green Mountain-Berkshire Hills anticlinorium (maximum Bouguer value +15 milligals 25 miles south-southeast of Rutland).

Density measurements and the relation between the gravity field and the geology indicate that the anomalous masses mainly responsible for these gravity features are not present near the surface. Warping and/or faulting of density discontinuities within or at the base of the crust are considered possible causes for the anomalies. The amplitude of the "warps," computed by assuming "normal' depths to discontinuities at 15 and 35 km and density contrasts of 0.3 gm/cc at both discontinuities, are roughly equal to the structural relief exhibited at the surface. Warps computed by assuming a "normal" depth of 35 km and a density contrast of 0.6 gm/cc are less satisfactory, for the amplitudes of these warps are very large, and the portions of the anomalous masses responsible for the major gravity high are very sharp features. Masses of such form might, however, be interpreted as discordant intrusions of mafic or ultramafic material.

DISTRIBUTION OF THE SOKOMAN FORMATION IN THE LABRADOR TROUGH SOUTH OF LATITUDE 56° N.

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The Sokoman formation consists of Huronian-type iron-bearing sediments, occurring in the western half of the Labrador Trough south of Lat. 56° N. This formation, which is 350–750 feet thick, is found as several distinct bands over an area 15–35 miles wide. This area may be divided into three zones. Along the western edge of the Trough, the Sokoman formation is flat-lying and continues 100 miles south of Knob Lake. After a break of 4 miles, it becomes gradually more metamorphosed and folded to the south extending for another 50 miles into the Wabush Lake area. In the central zone, it is repeated over a width of 15 miles by folding and faulting. Farther east, it occurs as a narrow zone which is highly folded. The eastern and central zones join about 50 miles southeast of Knob Lake to form a narrow band which continues southeast for another 50 miles to Gabbro Lake. Here the Sokoman formation becomes metamorphosed and bends westward to a point which is 15 miles from the western edge of the Trough.

Although the iron-bearing sediments of this area are widely distributed and show a variety of facies differing in thickness and degree of metamorphism, it is believed that they all belong to one stratigraphic horizon, the Sokoman formation.

EVOLUTION OF HORN CORALS THROUGH THE ORDOVICIAN

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Horn corals, which first appeared in late Black River time, have skeletal characters that gradually became more stable and elaborate as the group evolved through remaining Ordovician time. The earliest corals were colonial. Okulitch's hypothesis that Ordovician solitary corals originated

from colonial forms is supported by the prevalence of asexual increase in Black River and early Trenton *Lambeophyllum* and *Streptelasma*. At this early stage, coralla were predominantly conical with relatively scant septal deposits. Clusters of two or more individuals attached along planes of septal insertion occur in representative assemblages. Although conical form and asexual increase characterize some Richmond species, the lineages that diverged from the primitive habit have greater stratigraphic significance.

Through most of the Trenton, solitary corals were labile organisms. Coralla ranged from conical to trochoid in form; curvature, if developed, was erratic; and elaborate axial structures were not developed. By late Trenton time, however, curvature of the cardinal side had become established in most streptelasmids, though septal deposits were not much more elaborate than in earlier forms.

In the Mississippi Valley region, the Platteville, Decorah, and early Prosser coral faunas show the same sequence of development observed in the Black River and Trenton formations of New York. The upper Prosser assemblage, however, is more advanced and varied than that of the Cobourg equivalents in New York State. Some of these corals exhibit features that foreshadow the extraordinary development of distinctive streptelasmid forms characteristic of the Bighorn, Red River-Stony Mountain, and Arctic Ordovician faunas.

BASIN EXPANSIONS AND STABILITY IN LEVELS OF LAKE BONNEVILLE

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The present Great Salt Lake is delicately adjusted to precipitation changes and in historic times has fluctuated through 17 feet, so probably its predecessors, when below the overflow elevation, would have had equally unstable levels.

Expansions over thresholds into closed desert basins would retard the rising lake, especially if the precipitation-evaporation balance before the expansion were only slightly tipped in favor of precipitation. With a falling lake the abandonment of the closed basin would decrease the area of evaporation, and the lake level would remain stationary again for a while. The numerous basins within the floor of Lake Bonneville were studied systematically, and one expansion especially, namely the Great Salt Lake Desert, over a low threshold at 21–22 feet above the present Great Salt Lake resulted in a sudden doubling of the lake area. This is marked by a fairly prominent beach, in places as strong and conspicuous as the higher Stansbury, Provo, and Bonneville.

The Stansbury is one of considerable complexity and multiple levels, and these are tied to several expansions. As the lake rose and fell the expansions and abandonments caused stillstands in the lake level, and, therefore, the Stansbury, only 250–350 feet above Great Salt Lake, is very complex. Added to this, Carbon^{14} datings of core samples from Great Salt Lake and of tufa from the Stansbury levels suggest that the last fresh-water lake rose only to the higher Stansbury elevations. This climatic minimum lasted from approximately 20,000 to 11,000 years B.P.

LEAD ISOTOPES AND THE PATTERN OF MINERALIZATION IN SOUTHEAST MISSOURI

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The Lead Belt of Southeast Missouri is a Mississippi Valley type lead-zinc deposit occurring in nearly horizontal beds of dolomitized Upper Cambrian Bonneterre formation. Galena samples along the elongate, northwest-trending district were collected with reference to the structures which affected vertical and lateral movement of ore solutions. Isotopic analyses of 150 samples have shown maximum variations in the Pb^{206}/Pb^{204}, Pb^{207}/Pb^{204}, Pb^{208}/Pb^{204}, and Pb^{207}/Pb^{206} ratios of 11.5%,

2.4%, 4.7%, and 8.9% respectively. All samples show excess radiogenic lead over average crustal lead.

Variations in lead-isotope composition, along structures known to have affected migration of ore solutions, indicate that the earliest mineralizing solutions contained maximum amounts of radiogenic lead as compared to solutions responsible for later phases of mineralization. This parameter is used to determine the pattern of mineralization in areas where the controlling geologic features are less obvious.

In thoroughly sampled areas the data indicate the relative importance of lateral versus vertical movement of ore-bearing solutions. The former is commonly controlled by northeast-trending ridge structures, the latter by breccia zones, faults, reef structures, and permeability variations which may direct solutions both vertically and horizontally. Basement knobs protruding into the lower Bonneterre are established as important areas for concentration of ore solutions prior to introduction into overlying dolomites.

DISCORDANT URANIUM-LEAD AGES AND MINERAL TYPE

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The discordant ages obtained from the isotopic ages Pb^{206}/U^{238}, Pb^{207}/U^{235}, Pb^{207}/Pb^{206}, and Pb^{208}/Th^{232} in various minerals are considered in terms of mineral type. All available pertinent data, including some new measurements made at the Lamont laboratory, are compared.

Under favorable circumstances, concordant ages can be obtained from almost any radioactive mineral. When anomalies appear, each mineral type appears to show a consistent pattern. Pitchblendes and microlites, for example, have the pattern $Pb^{206}/U^{238} < Pb^{207}/U^{235} < Pb^{207}/Pb^{206}$. Uraninites, samarskites, and thorites are characterized by $Pb^{208}/Th^{232} < Pb^{206}/U^{238} < Pb^{207}/U^{235} < Pb^{207}/Pb^{206}$. Monazites show $Pb^{206}/U^{238} > Pb^{207}/U^{235} > Pb^{207}/Pb^{206} > Pb^{208}/Th^{232}$, and euxenites give $Pb^{206}/U^{238} < Pb^{207}/U^{235} < Pb^{207}/Pb^{206} < Pb^{208}/Th^{232}$. Patterns obtained with an individual mineral type apparently are not a function of age. Isotopic studies from the same area show that each mineral differs considerably in its stability to alteration. The Pb^{207}/Pb^{206} age is regarded as the best approximation of the true age for all mineral types, at least for samples older than approximately 300 million years. This age is minimal and may be considerably younger than the true age for pitchblende.

It is concluded that the best way to arrive at the absolute age of an area is to make a number of analyses, both on the same and different mineral types.

ROLE OF ENGINEERING IN PLEISTOCENE GEOLOGY*

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During the past 30 years recognition of the relations between geology and civil-engineering projects has been steadily increasing, as demonstrated by the volume of discussion, verbal and published, about them. However, in most of this discussion the value of geology to the engineering aspect of the projects has been stressed, at the expense of consideration of what engineering may contribute to the fund of geological knowledge. This latter aspect of the situation is exemplified by several instances of the contributions which engineering has provided to Pleistocene geology in Illinois. These may serve to incite in geologists a more receptive attitude toward the potential of information afforded by engineers in their work and increased cultivation of their co-operation.

* Presented with permission of Chief, Illinois State Geological Survey

LIFE CYCLE AND EVOLUTION OF BRYOZOA

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Simplification of life cycle through reduction of some phases, and up to complete suppression of one of the two alternating generations, is a major evolutionary trend throughout the organic world. Life cycle of Cyclostomata, the oldest order of bryozoans, is more complex than that of Cheilostomata, the youngest order. Additional phases in Cyclostomata are (1) embryonic fission, whereby secondary embryos arise from primary embryo, and (2) "common bud" or "colonial bud," arising from metamorphed larva and germinating all zooecia as it expands throughout the colony.

Polarized light discloses that Paleozoic fenestrate bryozoans possess primary structure (colonial plexus) homologous to the colonial bud of Cyclostomata, and differing only in more obvious and complex development. Colonial plexus, which extinguishes in polarized light, builds a continuous tinfoil-like core through all branches and dissepiments in *Fenestella* and other fenestrate bryozoans, and the whole group deserves segregation into a new order.

Epitheca or germinal plate (Ulrich) of Paleozoic Cyclostomata and Trepostomata also extinguishes in polarized light but not so uniformly as the colonial plexus. Whole colony of primitive Ordovician *Corynotrypa* completely extinguishes in polarized light.

Germinal plate or basal plate (Ulrich) of bifoliate cryptostomes does not black out in polarized light, but its position indicates homology with colonial bud and colonial plexus. So also the axial tube in *Rhabdomeson*, whose wall and diaphragms are structurally different from walls and diaphragms of surrounding zooecia.

Prominent development in Paleozoic bryozoans of structures homologous to common bud or colonial bud of living Cyclostomata indicates greater complexity of their life cycle.

RECONNAISSANCE GEOLOGY OF THE VIRDEN QUADRANGLE, GRANT AND HIDALGO COUNTIES, NEW MEXICO*

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The Virden 30-minute quadrangle occupies a critical position between the Santa Rita-Silver City and Clifton-Morenci mining districts. It includes the small Steeple Rock mining district and part of the Burro Mountain mining district.

The rocks consist of a Precambrian crystalline complex exposed in the Burro Mountains and in an outlier to the west, about 800 feet of Cretaceous beds (Beartooth sandstone, Colorado shale, and altered volcanics), 7000 or more feet of Tertiary volcanics, and several series of Tertiary-Quaternary conglomerates, fanglomerates, and alluvium.

Paleozoic sedimentary rocks, host to mineralization in surrounding areas, are missing. The Tertiary volcanic succession is from andesites and dacites to rhyolites with subordinate andesites and latites, followed by basic andesites, basalts, and late rhyolites. This succession is typical of much of southwestern New Mexico.

Important structures include part of the Burro Mountain uplift in the southeast and a series of major normal faults in the west. The western faults, which seem to converge toward the Clifton-Morenci area, control mineralization in the Steeple Rock district. Fault movements continued from Cretaceous to Pliocene-Pleistocene time.

Gold, silver, and manganese are mined at present. Copper, lead, zinc, uranium, perlite, diatomite, and bentonite are known.

In surrounding areas metallic mineralization is largely confined to pre-Tertiary sedimentary and

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intrusive rocks, but here it is mostly in late (?) Tertiary volcanics. Manganese minerals also form fissure veins in Miocene-Pleistocene (?) Gila conglomerate.

CHELATION, A POSSIBLE GEOLOGIC PROCESS

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Water vapor, released in rocks by shearing, reacts with ferrous iron and carbon to produce abundant hydrogen and carbon monoxide. More than 500 new gas analyses of heated rocks support this statement. Chelates, especially the carbonyls of iron, result from the presence of these gases and render the iron mobile. We have removed 5–10 per cent of the iron of biotite in a flowing atmosphere of carbon monoxide and hydrogen at 50°C and 1 atmosphere absolute in 27 days. We suggest that this and similar processes may remove mafic constituents from rocks along and near shear zones to leave felsic rocks behind and to produce mafic rock types at sites of chelate breakdown, especially near the surface. We refer to basic fronts related to shear zones near intrusives and to Hess' double bands of serpentine occurrence lateral to major earth shears. We suggest the conversion of simatic material to sialic along the great soles at continental borders. Subsequent magmation of such progressively changing host rock yields wide areas of intermediate lavas, modified but not created by crystal fractionation. On completion of sialic development the new area adds to the continent, and the sole advances seaward. Since island arcs and trenches are not in isostatic balance, they must be structurally formed. We suggest that they may be initiated by seismic disturbances and may be simulated by vibrating an inclined sheet immersed in sand to produce both "island" and "trench" in proper relative position.

DISTRIBUTION OF COPPER, LEAD, AND ZINC IN HYDROTHERMAL DOLOMITES ASSOCIATED WITH SULFIDE ORE IN THE LEADVILLE LIMESTONE (MISSISSIPPIAN, COLORADO)

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The association of hydrothermal? sulfides and enveloping dolomite, which replace the original Leadville limestone (Early Mississippian), suggests a related origin for dolomite and ore. Paragenic data at Gilman and Leadville, Colorado, indicate dolomitization preceded ore. But the immediately succeeding metal-depositing fluids had to flow between and probably diffuse through many dolomite grains. Fifty analyses of coarse and fine grains of dolomite, interstitial to sulfides, at walls of inferred conduits and at ore contacts show Cu, Pb, and Zn contents that vary little from respectively 3, 3, and 10 ppm. Similar amounts of Cu, Pb, and Zn occur throughout the unaltered Leadville limestone over an area of 5000 square miles (75 analyses from 25 localities).

The lack of enrichment of these metals in the dolomite that envelops ore could reflect the incapacity of the dolomite to play host to higher concentrations of Cu, Pb, and Zn, either by substitution or adsorption.

Alternately it is possible that (1) all dolomitization was by metal-poor solutions; (2) the Cu, Pb, and Zn in ore were introduced rapidly by mechanical flow of ore-bearing fluids along localized channels; (3) ore-depositing fluids left the dolomite as in (2) or left the localized sites of sulfide deposition essentially devoid of Cu, Pb, and Zn.

Whether the above or other interpretations pertain, the existing patterns and concentrations of Cu, Pb, and Zn in the Leadville carbonate place important restrictions upon concepts of mineralization.

MUSCOVITE-PARAGONITE JOIN AND ITS USE AS A GEOLOGIC THERMOMETER

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Hydrothermal investigations of the mica group have been extended to include soda-bearing muscovites and potash-bearing paragonites. Muscovite-paragonite assemblages are common in metamorphic rocks, and the limits of solid solution are known to depend on the grade of metamorphism. The phase relations on the join muscovite-paragonite have been studied up to 2000 bars water pressure. At 2000 bars muscovite and paragonite are stable up to 715°C and 660°C, respectively. Below 660°C the join is binary with a broad two-phase region in which muscovite and paragonite coexist. The extent of solid solution decreases rapidly on both sides of the solvus with decreasing temperature. The maximum amount of paragonite dissolved in muscovite at 2000 bars is 24 mol per cent.

Below 660°C the position of the solvus is largely independent of the total pressure. The pressure dependency of the temperature, at which the solvus is truncated, is given by the breakdown curves for the end members. A continuous series of solid solution between muscovite and paragonite exist only at pressures higher than 4500 bars.

The muscovite-paragonite solvus can be used to determine temperatures of formation of muscovite-paragonite assemblages. The data have been extended to include muscovites from muscovite-albite assemblages. It could be shown that paragonite and K-feldspar react to form muscovite + albite. In mica-feldspar assemblages micas tend to show smaller Na/K ratios than the coexisting feldspars.

This new geothermometer has been applied successfully to muscovites from Black Hills, South Dakota, pegmatites.

CRYSTAL CHEMICAL STUDIES OF LOW-VALENCE VANADIUM OXIDE MINERALS FROM THE COLORADO PLATEAU

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Crystal-structure studies, during the past 4 years, of vanadium minerals from the Colorado Plateau have established the following new mineral species: montroseite, $V_2O_3 \cdot H_2O$; paramontroseite, VO_2; mineral "A", $V_2O_3 \cdot V_2O_4 \cdot 3H_2O$; mineral "B", $V_2O_3 \cdot 2V_2O_4 \cdot 5H_2O$; and duttonite, $V_2O_4 \cdot 2H_2O$. The last three are previously undescribed; the structure of duttonite is given in an accompanying paper, and minerals "A" and "B" are characterized in this paper.

Minerals "A" and "B" are intimately intergrown constituents of small black crystals from Carlile, Wyoming. "A" is monoclinic, space group $C2/m$ (C_{2h}^3) with $a = 12.17$ A., $b = 2.99$, $c = 4.83$, $\beta = 98°15'$, and cell contents $H_6V_4O_{10}$. "B" is monoclinic, space group $C2/m$ with $a = 19.64$ A., $b = 2.99$, $c = 4.83$, $\beta = 103°55'$, and cell contents $H_{10}V_6O_{16}$. The structures contain zigzag double octahedral chains as in montroseite, but linked into sheets instead of a three-dimensional framework. In mineral "A", only double chains are present; in "B", double chains alternate with straight single octahedron chains as in duttonite. The sheets are held together with hydrogen bonds. "A" and "B" apparently coalesce in oscillatory crystal growth in parallel orientation, and both probably originate as primary minerals. These five species, plus others under investigation, indicate a stepwise gradation from vanadium (III) to vanadium (IV) in nature.

CRYSTAL CHEMISTRY OF DUTTONITE

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Duttonite, a new vanadium oxide mineral from the Peanut Mine, Montrose County, Colorado (Thompson, Roach, and Meyrowitz, in press), has been studied by x-ray diffraction and crystal-

structure analysis. The crystals are pale-brown transparent flakes. The unit cell is monoclinic with space group $I2/c$ (C_{2h}^{4}), $a = 8.80$ A., $b = 3.95$, $c = 5.95$, $\beta = 90°40'$, and cell contents $H_8V_4O_{12}$ It is strongly pseudo-orthorhombic, with space-group symmetry close to $Imcm$, (D_{2h}^{25}), and in this setting the structure can be defined by the following parameters: 4 V in (e) with $y = 0.336$; 4 O_1 in (e) with $y = 0.754$; 8 O_2 in (g) with $x = 0.100$. The structure consists of straight single octahedron chains linked into sheets parallel to (100). The sheets are bound together with hydrogen bonds. A significant feature of the sturcture is the presence of a short V-O bond (1.65 A.) giving rise to discrete VO^{+2} groups corresponding to the vanadyl ion well known to chemists. The formula, $V_2O_4 \cdot 2H_2O$, derived from the structure analysis, has been confirmed by microchemical analysis.

Duttonite is completely transformed to V_2O_5 above 175°C in a few hours. After two weeks at 165°C, the crystals still give the duttonite pattern but are a dark brownish black. Chemical analysis of this product shows that the duttonite is partially oxidized to $V_2O_5 \cdot H_2O$, apparently through loss of half the hydrogen atoms from the unchanged structure. A single specimen from the Monument No. 2 mine contains crystals that have the properties of the oxidized duttonite.

PRECAMBRIAN SUBSURFACE OF KANSAS*

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Precambrian rocks are not exposed in Kansas, but information regarding them has been assembled from subsurface records. More than 1300 oil-test wells have penetrated through the cover of younger formations. The oldest rocks belong to a Precambrian metamorphic group that has been cut by members of an intrusive suite. The metamorphic group consists principally of quartzite, granulite, schist, phyllite, and gneisses. Some of the gneisses are foliated granites, injected at about the time of regional metamorphism. The intrusive suite is composed mainly of Precambrian granite, but a few wells near the center of the state penetrate gabbro and syenite of uncertain age. Widely scattered minor intrusives include pegmatite and diabase.

The general arrangement of the Precambrian rocks is shown on a contoured map and in a "fence" diagram. Structures in strata overlying the Precambrian are controlled partly by irregularities of the eroded Precambrian surface. The disposition of Precambrian rocks has been affected by movements in successive Paleozoic periods. In two chief areas, centra and eastern Kansas, anticlinal structures have resulted from recurrent uplift. Both these and the intervening basins are buried at various depths beneath Paleozoic rocks. Wherever possible the type of basement rock has been described and an example of each lithologic group illustrated in a photomicrograph.

HAGENDORFITE UNIT CELL

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Hagendorfite was described by Strunz in 1954 as a member of the varulite-hühnerkobelite series. Precession and Weissenberg study of the type material kindly sent to the writer by Professor Strunz shows it to be monoclinic and isostructural with alluaudite. If the latter is reoriented by merely changing the direction of its a axis so that its space group is I $2_1/a$ (instead of C 2/c; both are 15-C_{2h}^{6}) its best cleavage becomes (001) [instead of ($\bar{1}01$) of Fig. 2 on p. 1104, Am. Mineralogist, 1956], and its β angle is much less oblique. The results are as follows:

	a	b	c	β
Alluaudite (Buranga)	11.030	12.533	6.404	97°34′
Type hagendorfite	10.933	12.594	6.515	97°59′

* Publication authorized by Frank C. Foley, Director, State Geological Survey of Kansas, University of Kansas, Lawrence, Kans.

The writer has confirmed that hagendorfite does belong to the varulite series; the latter is thus neither orthorhombic (as surmised in Dana II, p. 669) nor triclinic (as thought by Strunz). A detailed chemical and x-ray study of all these minerals is in progress.

ISOKITE FROM A BOHEMIAN PEGMATITE

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The new mineral isokite (pronounced I - sōk' - ite) was described from a Rhodesian carbonatite plug last September (Mineral. Mag.). From the powder-diffraction data given by Deans and McConnell, the writer recognized an unidentified mineral occurring in our collections labelled "triplite from Schlaggenwald (now Slavkov) Bohemia (Foote, Philadelphia)." This was confirmed by study of a sample of the Rhodesian isokite kindly sent to the writer by W. H. Bennett of the British Colonial Geological Surveys through the kindness of T. E. Howling. The Slavkov triplite occurs in two generations; an earlier one is very dark brown, and a younger one is medium light brown; this is also true in Bavaria (Schmid, 1955), Finland (Volborth, 1954), and probably elsewhere. The Slavkov isokite is dull-lustered light-brown fine-grained massive material, which along with gray apatite serves as the matrix in which the lighter-colored triplite occurs as small vitreous irregular anhedra. The Slavkov triplite seems to have been distributed very widely; thus most museums probably have samples of Bohemian isokite. This was true for the Chicago Museum of Natural History, samples from which were kindly supplied by H. Changnon through the courtesy of S. K. Roy. The following table shows the composition of the Rhodesian isokite (R. Pickup) contrasted with that from Bohemia, as kindly determined spectrographically (to ±5%) by O. Joensuu; presumably the latter sample had about 35% apatite contamination.

	CaO	MgO	MnO	TiO_2	Fe
Rhodesia	29.6	21.2	0.13	....	0.32
Slavkov	40.	15.5	1.5	0.22	1.5

STRUCTURE OF PRE-CRETACEOUS BASEMENT NEAR PLAINSBORO, NEW JERSEY, AS INTERPRETED FROM SEISMIC-REFRACTION MEASUREMENTS

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Eight seismic-refraction stations were established across the coastal plain of New Jersey by Ewing, Woollard, and Vine (1939). A time offset on the unreversed seismic plot obtained for the station near Plainsboro, New Jersey, in addition to a study of bore-hole records in the area, led them to postulate the existence of two down-faulted blocks involving the Triassic Newark Series beneath the Upper Cretaceous coastal-plain sediments.

The writers established 16 refraction seismograph stations in the Plainsboro area in an effort to delineate the boundaries of these fault blocks. The following conclusions are drawn: (1) the normal Triassic crystalline basement depositional contact southwest of Plainsboro extends without structural complication for 6+ miles to the northeast beneath cover of the coastal-plain sediments; (2) the zero isopach of the buried Triassic rocks passes between shot point 53 and the geophones of the Plainsboro seismic station of Ewing *et al.*; and the time offset was caused by a thin wedge of lower-velocity Triassic material beneath shot point rather than by a fault; (3) the bore-hole data indicating baked shale is re-examined and placed in question; (4) the fault blocks of Ewing *et al.* are not considered necessary, since the time offset is explained, and the bore-hole data are in question.

AGE OF THE RED RIVER FAUNAS (ORDOVICIAN), MANITOBA TO NEW MEXICO

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Red River faunas show amazing uniformity from New Mexico to Greenland, indicating original continuity of seas. They form one of three major units of deposition recognizable from Texas to Manitoba: (1) Harding-Winnipeg sands, with equivalents at the base of the Montoya and Bighorn groups. Work of others suggests Black River or Chazy age for these beds; (2) Red River beds; (3) Richmond beds. The New Mexico succession supplies new members and evidence of intervening erosion intervals.

The Aleman and Cutter of New Mexico contain faunas extending from latest Richmond to Waynesville, beneath which two zones lack diagnostic Arnheim or Richmond types. If not Arnheim, they are Maysville.

Absence of many Red River types in eastern beds, their occurrence in older beds, evidence of Red River below complete Richmond in New Mexico, and an intervening erosion period demonstrate pre-Richmond age of the Red River. Much new and old evidence supports equivalence with the late Trenton and Eden, but not with the Maysville, probably a period of western uplift.

Cobourg-Eden seems an excessive range for the homogeneous Red River faunas. Much evidence suggests that the Eden and Late Trenton are largely contemporaneous though different facies, that the *Triarthrus eatoni* zones of the Fulton and New York Trenton are equivalent, and that southward disappearance of the Eden and appearance of new upper members of the Cynthiana is a facies phenomenon. Thus the required time span of the Red River is materially reduced.

AGE OF THE BURIED SOIL AT SIDNEY, OHIO

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New evidence from the Sidney cut in Shelby County, Ohio, appears to support a Wisconsin age for both the buried soil and the till in which it was formed. No age assignment had been agreed on previously, although many prefer a late Sangamon age.

This evidence comes mainly from studies by A. La Rocque of mollusks collected by J. Forsyth from a 1-foot silt beneath the thick till in which the soil was developed. The base of this silt grades downward into another till. Mollusks recorded are the land pulmonate gastropods *Carychium exile canadense, Cionella lubrica, Columella alticola, Discus cronkhitei, Hawaiia minuscula, Succinea avara, Succinea grosvenori, Vallonia gracilicosta, Vertigo alpestris oughtoni*, and the fresh-water pulmonate gastropod *Fossaria parva*. Because of the presence of *Columella alticola* and the abundance of *Vertigo alpestris oughtoni*, La Rocque prefers a post-Illinoian age for the fauna.

Laboratory analysis disproves the intensity of soil development suggested by field appearance of the buried soil, strongly favors a Wisconsin age for the soil, and suggests its correlation with other buried soils in Ohio interpreted as Mid Wisconsin.

Correlation of the till below the buried soil with a till below a peat dated at >37,000 years (W-415) from upper Brush Creek, 2 miles southwest of the Sidney cut, strongly suggests that many dates of the order of >37,000, as reported from a number of localities in western Ohio, may be Wisconsin.

LAYER-CHARGE RELATIONSHIPS OF THE MUSCOVITE AND BIOTITE MICAS

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In the ideal formulas for muscovite, $Al_2(Si_3Al)O_{10}(OH, F)_2K$, and biotite, $(Mg, Fe^{+2})_3(Si_3Al)O_{10}(OH, F)_2K$, the charge relationships of the octahedral and tetrahedral layers are identical; the

octahedral layer is neutral; the tetrahedral group has a charge of one. However, most natural micas contain other cations proxying for some octahedral cations. If the proxying cation has the same valence, the charge on the layers is not affected, but, if it has a different valence, layer-charge adjustments are necessary.

A divalent ion proxying, ion for ion, for aluminum in the octahedral layer of a muscovitic mica induces a negative charge on that layer equivalent to the amount of proxying cation, as the number of positive charges in that layer is less by that amount than the number of negative charges to be neutralized. As the total charge on the composite layer is approximately one, this necessitates decrease in charge on the tetrahedral layer. In the biotite group, proxying of trivalent for divalent cations introduces excess positive charges. By nonoccupancy of octahedral positions, some positive charges are neutralized, and the rest give a positive charge to the octahedral layer, necessitating equivalent increase in tetrahedral charge, to total a charge of one.

The two groups differ, therefore, in layer-charge relationships; in almost all muscovite micas the total charge is the sum of two negative charges, and tetrahedral aluminum is less than one; in almost all biotite micas it is the sum of a positive and a negative charge, and tetrahedral aluminum is more than one.

PROGRESS REPORT ON THE MAMAINSE "DIABASE," ALGOMA DISTRICT, ONTARIO, CANADA

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The Mamainse "diabase," located about 38 miles north of Sault Ste. Marie, forms a high plateau with an average elevation of about 1600–1800 feet and is intersected by deep fault- and joint-controlled valleys. This area is one of the most rugged in Ontario. The Griffin Lake diabase, which apparently postdates the Mamainse "diabase," underlies an area of at least 3 square miles at the eastern margin of the Mamainse "diabase" and rises to an elevation of 2100 feet towering about 1400 feet above Lake Superior.

The Mamainse "diabase" is a metadiabase and metabasalt composed of plagioclase (An_{60-70}) and hornblende with locally abundant epidote and chlorite. Porphyritic metabasalts were noted but are rare. Pillow structures suggest deposition in a submarine environment. The Griffin Lake diabase is mostly plagioclase (An_{50-62}) and subcalcic augite ($2V = 35°–44°$).

A complex series of steeply dipping metamorphosed lavas and sediments and siliceous iron ore is interbedded with the Mamainse "diabase" near its northern and southern margins. This complex sequence was overlain by the main mass of the Mamainse "diabase" prior to folding.

Granite dikes locally cut the "diabase" and interbedded formations and are in turn cut by later diabase dikes probably equivalent to Moore's Lower Keweenawan. Faults and joints of several generations are prominent and locally show mineralization.

The regional history is one of sedimentation and volcanism related to geosynclinal development during Kewatin times followed by subsequent deformation and magmatic activity.

CRYSTAL STRUCTURE OF EUCAIRITE

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Eucairite crystallizes in pseudo-tetragonal orthorhombic crystal shaving a large supercell of $a = 4.105$Å; $b = 20.35$Å; $c = 6.31$Å based upon a basic tetragonal cell whose a dimension lies somewhere between 4.07Å and 4.105Å and whose c dimension is equal to 6.31Å and has the space group symmetry of P 4/nmm. There are 2 (Cu Ag Se) per basic cell with the Ag atoms at ¼, ¼, .448; ¾, ¾, .552. The Se atoms are at ¼, ¼, .860; ¾, ¾, .140. If the Cu atoms were at exactly ¼, ¾, 0; ¾, ¼, 0, the cell would be truly tetragonal, and the Cu would be resting in the middle of a tetrahedron of Se. However, the copper is displaced from 0 in the positive or negative z direction to-

ward one of the edges of the Se tetrahedron. The positive or negative direction of this displacement is not random but rather periodic, giving rise to the superstructure spots and causing a slight dimensional change.

ISOTOPE ABUNDANCE OF Sr^{87} IN IGNEOUS ROCKS

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Previous work has shown that the time-dependent increase in the isotope abundance of Sr^{87} for sources of sedimentary materials is about 0.35% per billion years. Further work on the isotope abundance of Sr^{87} in volcanic and plutonic rocks suggests that the variation of the Sr^{87} isotope derived from limestones is typical for a great part of the earth's crust.

Both the Rb and Sr concentration as well as the Sr^{87} isotope abundance have been determined for several basaltic and granitic rocks. Rocks ranging in age up to 2.7 billion years were studied. From the age and the Rb/Sr ratio the initial isotope abundance of Sr^{87} for a given rock was determined. The present-day Sr^{87} isotope abundance for granitic rocks is determined largely by the age and Rb/Sr ratio of the rock. However, the initial isotope abundance of Sr^{87} in granitic rocks is similar to that in basalts of the same age. The increase in time of this initial Sr^{87} isotope abundance suggests a Rb/Sr ratio of about 1/10 for the source of both basaltic and granitic rocks.

The material balance between igneous and sedimentary rocks indicates that the source of sedimentary materials is primarily granitic rocks. The isotopic composition of Sr in sea water, limestones, and granites suggests that such a source would have an average age of less than 500 m.y.

RATES OF MOVEMENT AND MIXING OF WATER MASSES IN THE ATLANTIC OCEAN

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The water masses of the Atlantic Ocean have been sampled for tritium (H^3) analysis since 1953 in order to establish their rates of circulation. Since all but one of the Atlantic water masses originate at the surface, the tritium content of surface waters had to be established. The average of seven 1953 surface waters from the western North Atlantic is $T:H = 1.3 \pm .3 \times 10^{-18}$. It is suggested that this is a maximum value for the North Atlantic based on meteorologic tritium data for the United States and Europe.

Eight 1954 tritium surface concentrations average 2.1×10^{-18} owing to the Pacific bomb tests. The values in the western Atlantic are higher than those in the eastern area.

Samples to a depth of 100 meters in the western Atlantic show that mixing takes place in less than 4 years. A sample near the transition from Surface Water to Central Water in the Eastern Atlantic gives a value of 0.62×10^{-18} which suggests the water is mixed to that depth within about 8 years.

The tritium content of waters at 2000 and 4000 meters is less than 0.3×10^{-18}, while the bottom water is less than 0.7×10^{-18}. The significance of these results in terms of the total metabolism rate in the Atlantic will be discussed.

K40/A40 DATING OF THE PRECAMBRIAN ROCKS OF MINNESOTA

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Determination of the absolute age of the Precambrian rocks of Minnesota is the target of a K40/A40 project. Knowledge of the Precambrian rocks of Minnesota rests primarily on field studies in

the northern part of the State where the succession is fairly well known. In central Minnesota and in the Minnesota River Valley the relative ages of the Precambrian rocks have been established by field and laboratory studies, the latter based largely on the type of zircon.

Some preliminary K40/A40 age determinations (B. R.—.117) given here were made on biotite from fresh rock samples (for the NW Angle pegmatite, muscovite was used). The figures are in billions of years:

NW Angle pegmatite	2.4	Morton gneiss	2.4
Kinmount pegmatite	2.4	Warman granite	1.8
Burntside Lake granite	2.5	Rockville granite	1.6
Sacred Heart granite (1)	2.4	Granite Falls late granite	1.6
Sacred Heart granite (2)	2.4	Babbitt granite	1.1 (?)

The great age of the samples from Kinmount and from Burntside Lake requires re-evaluation of the geology of the Vermilion granite, formerly considered most likely of Algoman age. Similarly, the antiquity of the rocks in the Minnesota River Valley requires reassessment of the tentative ages assigned on the basis of type of zircon.

The K40/A40 dating is a promising tool for work in the Precambrian in glaciated areas of few and isolated outcrops and of complicated structure. The present project will cover the State of Minnesota and some adjacent areas.

EXSOLUTION OF DOLOMITE FROM CALCITE

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Calcites from a variety of marbles have been investigated by single-crystal x-ray techniques, chiefly the Buerger precession method. Most of the specimens were relatively high-grade metamorphic carbonates, from amphibolite and granulite facies rocks. The typically milky calcite of these rocks commonly contains dolomite, revealed by the x-ray photographs, but not always observed under the microscope. This finely disseminated dolomite is in the same crystallographic orientation as the host calcite and is almost certainly an exsolution product.

An oriented intergrowth of dolomite in calcite was produced in the laboratory. The original material was an echinoid test, made up of spongy, but single-crystal calcite with approximately 10 per cent Mg CO_3 in metastable solid solution. This amount of Mg is stable in calcite at approximately 625°C, therefore exsolution of some of the Mg as dolomite took place when the sample was heated under CO_2 pressure at 500°C. The host magnesian calcite retained its identity as a single crystal, and the dolomite exsolved in the same crystallographic orientation as the host.

The host calcites of many of the metamorphic rocks still have significant amounts of Mg in solid solution; the exsolved dolomite in these cases indicates a higher temperature than would be deduced by the amount of Mg now in solid solution in the calcite. The amount of exsolved dolomite can vary from spot to spot in a single specimen, probably because of original compositional variation.

HYDROTHERMAL ALTERATION IN TUNGSTEN AND GOLD-PYRITE VEINS OF BOULDER COUNTY, COLORADO

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The alteration halo of the ferberite and the gold-pyrite veins cutting granitic rocks in Nederland and Gold Hill districts, Colorado, shows five zones characterized by the following minerals (inward): (1) phlogopite-siderite, (2) montmorillonite, (3) kaolinite, (4) orthoclase, (5) hydromuscovite. Zone (1) represents partial alteration of biotite which extends to, and becomes more intense at, the hy-

dromuscovite zone. The remaining zones represent the alteration of plagioclase. Microcline is mostly stable in all zones. A large part of the hydromuscovite shows random interlayering by 15–20 per cent of montmorillonite; in one case (Chance mine) the interlayering is regular with a 1:1 ratio. Pre-vein (deuteric?) sericite is widespread. Supergene phenomena are restricted to clay transportation, sulfide oxidation, and coating of surfaces by sulfates.

Upon ascent, the hydrothermal solutions are thought to have distilled a highly volatile, acid phase that permeated and altered the wall rock, followed by a heavier, silica-rich liquid that filled the channelways. The zoning is believed to have originated through a change in the Si:Al:K:(Na, Ca, Mg) concentration ratio away from the conduits, with temperature and pH changes contributing only as secondary, largely conditioned factors. The hydrothermal mineral formed at each zone depended chiefly on the solutions and on the replaced mineral insofar as its dissolution modified the overall composition of the solutions. The instability of the rock minerals was the main factor in localizing the alteration.

HAFNIUM CONTENT, HAFNIUM TO ZIRCONIUM RATIO, AND RADIOACTIVITY OF ZIRCON FROM IGNEOUS ROCKS

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The hafnium content and Hf/Zr ratios were determined spectrographically on more than 150 zircon samples separated from comagmatic rocks from the batholiths of California, Idaho, Montana, Texas, Minnesota, and New Hampshire. Radioactivity measurements were made by thick-source alpha counting. The spectrographic results are believed to be accurate to ±10 per cent, and the alpha counts ±5 per cent.

Data on zircon from rocks from southern California, constituting a typical calc-alkalic batholith follow.

Rock type	*No. of samples*	*Per cent Hf (range and average)*	*Hf/Zr ratio (range and average)*	*Activity (α/mg/hr) (range and average)*
Quartz diorite	8	0.75–0.86 (0.81)	0.015–0.017 (0.016)	143–594 (256)
Granodiorite	6	0.79–1.1 (0.93)	0.016–0.024 (0.019)	433–1,235 (773)
Quartz monzonite and granite	5	1.00–1.55 (1.14)	0.020–0.030 (0.024)	396–4,660 (1,866)

A similar trend, indicating a general enrichment of hafnium to zirconium, coupled with increased radioactivity in zircon from the later-formed rocks, has been found in the Idaho batholith and in zircon from aplites as compared with zircon from associated intrusions.

Zircon from syenite and from nepheline syenite, from widespread localities, has significantly lower Hf contents [0.30 to 0.65 per cent] and Hf/Zr ratios ranging from 0.006 to 0.015.

Data show that zircon from rocks most commonly exposed in the earth's crust has an average hafnium content of approximately 1 per cent and an Hf/Zr ratio of 0.02. This ratio agrees with the estimate given by Michael Fleischer for the Hf/Zr ratio in the earth's crust based on all published data on minerals and rocks.

TRILOBITE DISTRIBUTION, UPPER FRANCONIA FORMATION, WABASHA COUNTY, MINNESOTA

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The fauna of the *Ptychaspis-Prosaukia* zone was sampled in detail from the upper two members of the Franconia sandstone along the shore of Lake Pepin. The Tomah member is nonglauconitic

feldspathized sandstone that underlies the glauconitic Reno member. Within the Tomah member a few glauconitic beds intermediate between Tomah and Reno rock types; they contain abnormally few trilobite species but a normal number of specimens.

Trilobites are distributed in a series of epiboles that serve as the basis for zonation. Ranges of species for which zonal subdivisions are named extend above and below their epiboles and overlap one another. This gradational pattern of distribution contrasts strongly with the sharp faunal breaks and distinct zones of previous literature.

Trilobite distribution was controlled only partially by conditions that produced the rock types. The *Ptychaspis granulosa* epibole occurs near the base of the Tomah member at westernmost localities, but near its top farther east. The *Ptychaspis striata* epibole occurs in the top bed of the Tomah in the west but in lower Reno beds in the east. Assuming that an epibole is contemporaneous within a local area, the eastward stratigraphic ascent of epiboles and the intertonguing of the two members constitute evidence for at least partial contemporaneity of Tomah and Reno environments of deposition.

MIOCENE POLLEN FLORAS FROM OREGON

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Diatomaceous ash containing plant megafossils at or near the contact with the underlying Columbia River basalt in eastern Oregon contains abundant and locally well-preserved pollen and other plant microfossils. Three pollen floras, showing close floristic relationship with megafossil floras from the same localities, are described from middle to upper Miocene lacustrine sediments from the John Day Basin, east-central Oregon, the Blue Mountains, about 45 miles to the northeast, and the Stinking Water Basin, about 50 miles to the southeast.

Identified material is referred to 36 generic entities, including: Algae: *Botryococcus, Pediastrum, Tetraedon;* Gymnospermae: *Abies, Cedrus, Ephedra, Picea, Pinus, Tsuga;* and 26 genera of dicotyledenous plants, including: *Acer, Alangium* (?), *Alnus, Betula, Carya, Celtis, Corylus, Fagus, Fraxinus, Ilex, Juglans, Liquidambar, Myriophyllum, Nyssa, Pachysandra, Pterocarya, Quercus, Salix, Tilia.* Entities not generically determined include at least 9 distinctive spore types, probably representing members of the Polypodiaceae, as well as other fern and lower plant families; members of the Taxodiaceae-Cupressaceae-Taxaceae complex; Graminae, Caryophyllaceae, Rosaceae, Ericaceae, Ulmaceae, and Compositae.

Pollen spectra are discussed comparing the localized pollen florules as well as the main floristic differences among the three geographically distinct floras, which represent the regional Miocene vegetation. Montane coniferous genera forming a dominant element in the Blue Mountain flora contemporaneously with the lower-elevation Mascall and Stinking Water floras demonstrate that the Columbia River basalt did not completely submerge pre-existing uplands of eastern Oregon in Miocene times.

STRUCTURAL STUDIES IN THE MAYO DISTRICT, YUKON TERRITORY*

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A large-scale recumbent fold involving Precambrian (?) slate and quartzite has been mapped in the Davidson Mountains, north of Keno and Galena Hills, Mayo District, Yukon Territory. Its presence supports the hypothesis that the more complex structures of Keno and Galena Hills to the south, underlain by phyllite and schist, include attenuated recumbent folds separated by thrust

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zones. Axes of major and minor recumbent folds trend west in the western part of the area and southeast in the eastern part, indicating either thrusting in two different directions or, more likely, later deformation of originally parallel axes. Wrinkle lineation on foliation planes trends consistently southeast throughout the area and may be related to this later deformation. The important silver-lead-zinc deposits of the district occur in faults younger than the wrinkle lineation.

CONCENTRATION OF URANIUM IN SEDIMENTS BY MULTIPLE MIGRATION-ACCRETION

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Weathering and erosion of vast amounts of Precambrian granitic rocks have occurred in the eight western States which constitute our uranium province. If the smaller amounts of volcanic tuffs are added, the uranium contained in these detrital rocks is at least 800 million tons. Under humid conditions the uranium would have been carried to the sea, but under arid conditions, extensive continental sediments, and proper leaching agents, the results would be quite different. Bicarbonates of Ca, Mg, and Na can form soluble complex ions with U in water saturated with CO_2. Uranium could be carried long distances by such solutions until it encountered carbonaceous material, including hydrocarbons, which would cause precipitation and reduction. Under near-surface conditions re-oxidation would cause U to go into solution once more. Concentration of large deposits could proceed by stages of oxidation-solution-migration-accretion. Orogenic movements with new unconformities and new gradients would make more U available and add to the number of depositional variations encountered in space and time. Whether concentration occurred in Mesozoic or later rocks would not alter the principles involved—namely, oxidation to soluble uranyl solutions, precipitation, and reduction by organic matter and accompanying H_2S. The processes would work in lignitic beds as well as in Todilto limestone. The associated relatively unusual amounts of V, Cu, Mo, Pb, and As accumulate in a similar manner.

LIPALIAN INTERVAL EVALUATED

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The perplexing problem of applying time terms to the unfossiliferous rock units of the Canadian Shield has baffled Precambrian geologists for more than a century. The oldest diagnostic fossil horizon, the *Olenellus* zone, is often arbitrarily designated as the base of the Cambrian, and Walcott termed the interval between the Cambrian and the Beltian the Lipalian interval. Later the term was applied to the time interval between the crystalline rocks of the Canadian Shield and the onlapping oldest rocks of Paleozoic age. This represents a time break approaching in length the total geologic time recorded in the last three eras.

More information is required on the so-called "Lipalian Interval" in North America, and an attempt has been made to bridge part of this gap. The Lake Louise area in the Canadian Rockies was selected because this was one place where the Cambrian and the Precambrian rocks were reported to be nearly conformable. Field work has confirmed a thick section of quartzites with some interbedded shales, which are conformable with the overlying *Olenellus* zone, and which lie on older rocks essentially concordant but with an erosional interval having considerable topographic relief. The oldest rocks exposed in the area are the Hector and Corral Creek formations.

The problem is, are these pre-*Olenellus* rocks Precambrian in age, are they pre-Paleozoic, or do they belong to a geologic era intermediate between Paleozoic and the crystalline rocks of the Canadian Shield?

STRUCTURAL STUDIES OF MINERALS BY MEANS OF NUCLEAR MAGNETIC RESONANCE

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X-ray diffraction methods are of limited value in determining certain kinds of structural features in minerals. Two important cases are the difficulty in (1) locating hydrogen because it has such a low scattering factor, and (2) discriminating between tetrahedral aluminum and silicon because they have similar scattering factors.

Recently, several new methods for structural analysis have been developed which depend on nuclear rather than on electronic properties. One of these methods, based on the phenomenon of nuclear magnetic resonance, is particularly useful for determining the structural position of hydrogen. A mineral containing magnetic nuclei, such as those of hydrogen, and subjected to a strong magnetic field exhibits radio-frequency resonance absorption. The shape and width of a resonance line depend on the magnetic interactions among the nuclei. Van Vleck has developed a theory by means of which the second moment of an absorption line in a solid can be computed from the internuclear distance and the nuclear magnetic properties. A particular structural model may be tested by calculating its second moment and comparing the result with the experimental data.

UPPER HURONIAN SEDIMENTATION IN A PORTION OF THE MARQUETTE TROUGH, MICHIGAN

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A lithogenetic study of the upper Huronian metasedimentary and metavolcanic rocks in a portion of the Marquette trough of Michigan indicates that these rocks are of the geosynclinal type and that sedimentary facies are developed within the trough. The lithologies represented include conglomerates, quartzites, graywackes, slates, schists, coarse pyroclastics, tuffs, flows, and iron formations. Banded iron formation was deposited during periods of relative quiescence in the geosynclinal stage, which suggests that long periods of stability of the crust are not a primary requisite for its deposition. Abundant graphitic material in the rocks immediately underlying and overlying an iron-bearing member and minor amounts of graphitic material within the member itself suggest the presence of abundant life at the time of deposition. Heavy-mineral assemblages are of little value in correlation but do provide some information on the probable source areas and parent rocks of the sediments. The presence of abnormally high titanium dioxide in the metasedimentary rocks appears to correlate with periods of volcanic activity.

OUTLINE OF NORTH ATLANTIC DEEP-SEA GEOMORPHOLOGY

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The North Atlantic is composed of the following morphological units:

	Typical Dimensions		
	Width (miles)	*Depth* (fathoms)	*Local relief* (fathoms)
Continental Margin			
Continental shelf	100	<100	10
Continental slope	25	1000–1500	700
Continental rise	150	1500–2500	100

	Width (miles)	*Typical Dimensions Depth* (fathoms)	*Local relief* (fathoms)
Island Arcs			
Inner basins	250	2500	1000
Island ridge	50	<300	100
Fore-deep	50	>4000	1000
Outer ridge	100	2700	150
Oceanic Basins			
Abyssal plains	150	2600–3200	0
Abyssal hills	10–300	2600–3400	500
Oceanic rises	600 (Width between outer limits)	2500	50–500
Mid-Atlantic Ridge			
Rift valley	25	1800 (axis)	—
Rift mountains	75	1000	1000
High-fractured plateau	150	1600	500
Upper step	300	2000	500
Middle step	1000	2400	500
Lower step	1200	2600	500
High marginal seamounts	40	200 (top)	—

The Mid-Atlantic Ridge provinces are separated by scarp zones remarkably parallel to linear features of the continental margins and oceanic rises. The provinces of the Mid-Atlantic Ridge established in the North Atlantic probably continue through the South Atlantic, Indian, South and East Pacific, and Arctic oceans. This great mid-oceanic median ridge is remarkably similar in topography and seismicity to African plateaus and rift valleys, suggesting a common origin and similar age.

The primary elements of relief of the North Atlantic appear to define a major fracture pattern which forms the tectonic framework of a significant portion of the earth's crust.

PHYSIOGRAPHIC DIAGRAM OF THE NORTH ATLANTIC

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The first sheet of the Physiographic Diagram of the North Atlantic (17° to 50° N. Lat.) has been completed. The technique employed is similar to that introduced by A. K. Lobeck to represent terrestrial relief. All features have been sketched adhering to a rigid vertical scale. The diagram was constructed in two stages; the relief was sketched along available echo-sounding traverses, and trends were noted and relief interpolated between traverses.

On the basis of textural differences noted on sounding traverses, the North Atlantic has been divided into provinces, and a chart has been prepared. The principal trends have been combined to construct a tectonic map of the North Atlantic. All three maps are on exhibit at this meeting.

RADIOACTIVE COLUMBITE-TANTALITE

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Columbite-tantalite from many pegmatite districts in the United States and from several foreign districts is radioactive; the radiometric assays yield results that range from barely detectable amounts to some on the order of 0.5% eU_3O_8. A Canadian columbite contains uranium in much larger amounts. Autoradiographic and x-ray studies show that two varieties of radioactive columbite-tantalite are distinguishable. In one the radioactivity stems from nonuniformly distributed foreign inclusions (either primary or secondary) or from coatings on crystal faces or along fractures (chiefly secondary).

In the other variety the radioactivity is produced by uranium or thorium in isomorphous substitution for Fe^{+2} within columbite-tantalite itself. Specimens of this type show either uniformly distributed radioactivity or radioactivity variable in crystallographically oriented zones. Even strongly radioactive columbite-tantalite is crystalline (nonmetamict), showing no major structural damage.

Preliminary data suggest that within some individual pegmatite districts columbite-tantalites possess a characteristic order of radioactivity. Toddite, described by Ellsworth from Dill Township, Sudbury district, Ontario, has been considered uranoan columbite or a euxenite-columbite mixture. Type metamict material recrystallized at 1000°C for 1 hour in air yields neither the columbite nor the euxenite x-ray powder pattern.

NUCLEAR MAGNETIC RESONANCE DETERMINATION OF THE POSITION OF HYDROGEN IN $Ca(OH)_2$—PORTLANDITE*

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Directly determined structural positions for hydrogen constitute an important category of information that is lacking for the hydrogen-containing minerals. To obtain such information for a representative trioctahedral-layer hydroxide, the proton magnetic resonance absorption was ob-observed in crystal powders of $Ca(OH)_2$ at liquid nitrogen temperatures.

The experimental value for the broadening of the proton resonance by the magnetic interactions among the protons enables one structural parameter to be determined. In this study the Bernal-Megaw model for trioctahedral-layer hydroxides is assumed, and the parameter dealt with is a separation distance s which is a measure of the amount of pucker in the hexagonal nets of hydrogen nuclei. The experimental data lead to a value of 0. 618, $\pm$ 0.039 A for s. This corresponds to an O–H distance of 0.99, $\pm$ 0.02 A in $Ca(OH)_2$, which is close to values reported for ice and gypsum.

Busing and Levy recently have reported an oxygen to hydrogen-nucleus distance of 0.98 A from a neutron-diffraction study of $Ca(OH)_2$, whereas Petch has reported an oxygen to electron-concentration distance of 0.78 A from an x-ray diffraction study.

BASIC SCIENCE (AND MATHEMATICS) REQUIREMENTS IN THE GEOLOGY CURRICULUM

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The basic science and mathematics requirements accompanying a major in geology vary greatly depending upon the specific requirements of colleges, whereas electives in these fields may also vary depending upon the student's field of interest and competence. Considerable variation is found in the Bachelor of Arts vs the Bachelor of Science requirements in different colleges. Although it may be desirable or even necessary for a student to acquire a minor in mathematics and several of the other sciences, the limitation of time within the baccalaureate degree must be considered. The petrology professor may recommend the requirement of physical chemistry for all majors, whereas the paleontology professor may require several courses in zoology or botany. Obviously, because of the time limitation, there should be some common denominator, minimum of hours, or course content from the several fields that should be required of all geology students. Such requirements should be uniform irrespective of the student's interest, emphasis, or objectives in graduate study, or field of employment immediately after the bachelor's degree. A minimum number of hours in each of the fields of mathematics, physics, chemistry, and biology should be established as a common requirement, rather than an emphasis in one or two of the fields to the exclusion of others.

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NICKEL MINERALS FROM NEAR LINDEN, IOWA COUNTY, WISCONSIN*

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Nickel minerals occur in comparative abundance as accessories in the Upper Mississippi Valley zinc-lead district in southwestern Wisconsin and northwestern Illinois as well as in other localities in Wisconsin, Illinois, Iowa, Missouri, and Indiana. Millerite is the commonest, and in southwest Wisconsin it is generally associated with violarite and (probably) bravoite. Near Linden, Wisconsin, the millerite is usually altered to a green or brown powdery hydrous basic nickel-iron sulfate, which has been named honessite. Honessite is extremely fine-grained and obscurely fibrous; the mean refractive index is 1.615, and the double refraction is very low. The *x*-ray diffraction pattern of the mineral has broad lines not referable to any known mineral, and chemical analyses indicate that the mineral is essentially a hydrous basic sulfate of nickel and ferric iron. Millerite was deposited near the end of the main period of deposition of the primary sulfides. The other nickel minerals are probably products of oxidation and secondary enrichment of millerite. A hitherto unrecognized type of symmetrical twinning in millerite suggests a lower symmetry than rhombohedral scalenohedral.

GROUND WATER IN PLEISTOCENE SEDIMENTS IN CENTRAL WISCONSIN

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Lithologic and geomorphologic studies of the sediments of Pleistocene age in the drift-covered portion of central Wisconsin are important in determining the occurrence, movement, and quality of the ground water. The drift consists of layers of till separated by stratified material, intermorainal deposits of outwash, and thick and extensive deposits of extramorainal outwash.

A series of prominent moraines mark the final recession of the continental glacier. In the early stages of retreat the meltwaters drained to the west, cutting channels through the outermost moraines. Deposits of coarse gravel are found in many of these channels. In the later stages of retreat, the melt waters drained to the south and to the east, depositing sediments between the moraines.

Ground water, under water-table conditions, occurs in both outwash and till. Although the till is less permeable than the outwash, it contains enough permeable material to keep it from acting as either a horizontal or a vertical barrier to the movement of water. The permeability of the till is attributed to the large amount of sand picked up by the glacier as it moves over sandstones of Cambrian age. Fragments of limestone and dolomite in the till contribute calcium, magnesium, and bicarbonate to the ground water.

The present surface drainage is east and west from the crest of the morainic system of Cary age. Although the ground water moves in the same general directions as the surface drainage, much of the flow is through channel deposits and intermorainal outwash.

UPPER PALEOZOIC, MESOZOIC, AND PALEOCENE STRATA OF WESTERN MONTANA

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Upper Paleozoic, Mesozoic, and Paleocene strata are exposed in the Clark Fork River Valley and Garnet Range, Granite County, western Montana. The most commonly quoted sections for the region are those from the Philipsburg quadrangle to the southwest. Descriptions are presented from

* Publication authorized by the Director, U. S. Geological Survey

a relatively less-deformed area to implement and expand the Philipsburg sections. The formations described include:

Tertiary	
Paleocene strata (unnamed):	Conglomerate, sandstone, siltstone, carbonaceous shale; thickness, 300 feet
Cretaceous	
Montana group (undifferentiated):	Shale, sandstone, siltstone, mudstone, varicolored; thickness 3730 feet
Colorado group (undifferentiated):	Shale, sandy, calcareous, some conglomerate, with sills in upper portion; thickness 3640 feet
Kootenai formation:	Basal conglomerate and sandstone; varicolored shale with some limestone, sandstone; limestone with some shale, sandstone in ascending order; top marked by "Gastropod limestone"; thickness, 1272 feet
Jurassic	
Morrison formation:	Siltstone, claystone, varicolored, some sandstone; thickness, 155 feet
Swift formation:	Sandstone and subgraywacke; thickness 101 feet
Rierdon formation:	Limestone, oölitic, glauconitic, fossiliferous, some shale, sandstone; thickness 257 feet
Sawtooth formation:	Shale, calcareous, silty, partly covered; thickness 185 feet
Permian	
Phosphoria formation:	Quartzite, sandstone, conglomerate; phosphate rock; chert and cherty quartzite in ascending order; thickness 0–85 feet
Pennsylvanian	
Quadrant formation:	Limestone overlain by quartzite; thickness, 300 feet
Mississippian-Pennsylvanian	
Amsden formation:	Limestone, stilstone, shale, red or stained red; thickness, about 300 feet

FAUNA OF THE GLEN DEAN LIMESTONE (MIDDLE CHESTER) OF INDIANA AND NORTHERN KENTUCKY*

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Thick-bedded or massive limestones constitute the lower part of the Glen Dean in Indiana, and calcareous shale, argillaceous limestone, and coquina the upper part of the formation. The lower limestone generally contains the brachiopods *Linoproductus pileiformis*, *Productus cestriensis*, *Stenoscisma explanatum*, *Torynifer setiger*, *Martinia contracta*, and *Spirifer leidyi*, whereas the upper beds of the formation contain *Cleiothyridina sublamellosa*, *Composita subquadrata*, *Punctospirifer transversus*, *Reticulariina spinosa*, and *Spirifer increbescens*.

Lithologic relations of Glen Dean crinoids are inconclusive, as complete specimens are rare and difficult to extract. Plates of *Pterotocrinus* are most abundant in the limestones. Pentremites are equally abundant in limestone and calcareous shale. Bryozoans range throughout the formation. Trepostomes and fistuliporoids are more numerous in calcareous shale, but fenestellids are abundant in limestone and calcareous shale. *Tabulipora ramosa* is extremely abundant in argillaceous beds in the upper part of the Glen Dean. Small distinct acanthopores are recognized in *Anisotrypa solida*.

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Conulariids, corals, trilobites, and gastropods are sparingly represented in both limestone and calcareous shale.

Glen Dean guide fossils in Indiana are *Pterotocrinus acutus*, *P. spatulatus*, *P. bifurcatus*, *P. depressus*, *P. vannus*, and *Pentremites spicatus*. *Prismopora serrulata* and *Stenoscisma explanatum*, index fossils of middle and upper Chester elsewhere, are found sparingly in Indiana.

The Glen Dean contains more than 100 species distributed as follows: 21 *Pentremites*, 23 crinoids (1 new), 26 brachiopods (1 new), 4 gastropods, 1 coral, 1 conulariid, 1 pelecypod, 1 trilobite, and 28 bryozoans (3 new).

GREAT LAKES FROM THE GLENWOOD AND WARREN STAGES TO THE ALGONQUIN STAGE

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Three stages of Lake Chicago—the Glenwood, Calumet, and Toleston—occurred at the same elevations as three stages in the Huron and Erie basins—the Grassmere, Lundy, and early Algonquin. Leverett and Taylor (1915) stated that Lake Chicago and the eastern basins had separate outlets during Grassmere to early Algonquin time. The writer suggests that coincidence of three successive levels requires an explanation on a basis other than chance, and that the Grassmere, Lundy, and early Algonquin stages discharged to Lake Chicago and were determined by the Glenwood, Calumet, and Toleston stages, respectively.

The proposed Huron-Michigan connecting channel was along the front of the receding Mankato ice from a point west of Alpena, Michigan, to the vicinity of Petoskey, thence through a channel, partly ice-bordered, passing close to Boyne Falls, East Jordan, Bellaire, Rapid City, Elk Rapids, and Traverse City, and thence to the Michigan basin.

None of the facts reported by Leverett and Taylor preclude this interpretation. A feature in the St. Clair River valley, interpreted as an esker, is better explained as a remnant of an Algonquin-level river bed graded to the Port Huron outlet and indicating northward flow in early Algonquin time. Some of the facts reported by Bretz in 1953 support the present interpretation. The principle of Bretz's (1951) proposed mechanism for determining the levels of Lake Chicago stages is accepted, but the writer rejects Bretz's specific correlations between stages in the Michigan and the eastern basins.

PREPARATION FOR GRADUATE STUDY—GEOPHYSICS AND GEOCHEMISTRY COMPARED TO GEOLOGY AND MINERALOGY

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The curricular needs of a student planning graduate work tend to differ from those of a student seeking a terminal degree. Undergraduates major in the geological sciences for a variety of reasons, but almost all graduate students are preparing for a professional career. For the latter group, some important courses can be postponed until graduate years, while others, needed as prerequisites, should be completed during undergraduate study. Furthermore, each of the diverse specialties in the earth sciences is based on a slightly different grouping of fundamental courses.

The new fields of geophysics and geochemistry pose particular problems, as preparation for them generally requires more mathematics, physics, and chemistry than most geology majors take. Lack of these or of certain geology courses may substantially increase the time required to earn an advanced degree. Nineteen out of 47 graduate students admitted to Pennsylvania State University in the past 8 years had undergraduate deficiencies of this type. The recommendations of 18 leading universities offering graduate work in these fields as to what courses are considered most important are tabulated. In addition to full-year introductory courses in geology, chemistry, physics, and cal-

culus most universities recommend or expect incoming geophysics graduate students to have taken courses in elementary mineralogy, structural geology, geophysical prospecting, electricity and magnetism, electronics, and differential equations. For the incoming geochemist elementary mineralogy, petrology, structural geology, the petrographic microscope, quantitative analysis, and physical chemistry are recommended.

APPLIED SCIENCE AND ENGINEERING COURSES IN THE GEOLOGY CURRICULUM

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In the application of our science we find the greatest lure toward specialization at the undergraduate level. We tend to forget that our students will receive thorough training in the specific application of their geology by whatever company employs them, and so we crowd their curriculum with specialized courses in applied geology. This results in our actually handicapping our "product" in his potential adaptability. We would broaden his horizon considerably if we would allow him time in his undergraduate training for electing work in certain basic courses in engineering—*e.g.*, statistics, strength of materials, hydraulics, or surveying; and for courses in techniques more closely related to geology—*e.g.*, interpretation of maps and aerial photographs, preparation of materials to be examined under the microscope, principles of geophysics, and the organization of data into a report. Too often, we teach foraminiferal assemblages instead of the principles of micropaleontology; the stratigraphy of a specific area rather than the principles of stratigraphy. With the all too-short period of time we have for preparing our undergraduate student for either graduate or commercial work, we may render him a disservice by limiting his field before he learns what the possibilities are.

SPATIAL AND CHEMICAL RELATIONS DURING GENERATION AND CRYSTALLIZATION OF ENCHANTED ROCK BATHOLITH, LLANO AND GILLESPIE COUNTIES, TEXAS

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Detailed tectonic diagrams show the probable sequence of events during generation of magma that formed the batholith. Spatial relations of newly formed magma are shown during the time and at the site of magma generation and appear to explain field distribution of rock zones.

Chemical evidence apparently confirming the petrotectonic history is found in oxide plots for rocks of the batholith superposed on Tuttle's (1952) ternary diagram that shows relations between CaO–Na_2O–K_2O content and modal plagioclase. Position of plots indicates that (1) outer and intermediate zone rocks should have crystallized from a liquid of granitic composition that produced a one-feldspar granite, and (2) intermediate central, transition to core, and core rocks should have crystallized from a liquid that would produce a two-feldspar granite.

Rocks in both (1) and (2) are two-feldspar granites. The apparently anomalous crystallization of two-feldspar granite in (1) is probably due to fluxing by volatiles which lowered the liquidus enough to permit two-feldspar granite to crystallize from liquid that normally would have produced one-feldspar granite. Scattered veins of fluorite, abundant pegmatites and aplites, and sericitization indicate such fluxing action was possible.

Granite porphyry (llanite) dikes from this province approach closest to composition of the magma that formed the rocks in (1). Oxide plots for llanite indicate it should have crystallized from liquid that would produce a one-feldspar granite. Phenocrysts of one feldspar (microline and microcline-perthite) in aphanitic groundmass indicate that the crystallization predicted by position of oxide plots on the ternary diagram did occur.

POLYMORPHISM AT HIGH HYDROSTATIC PRESSURE

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An apparatus has been developed for obtaining x-ray powder patterns of substances under "hydrostatic" pressures up to 24,000 kg/cm² and permitting moderate heating. The pressure vessel is a single-crystal diamond through which a polished, straight .015-inch hole has been ground. A powdered sample is placed between two hardened steel pistons which generate pressure when squeezed together in a miniature press. Mo radiation penetrates the diamond and sample, giving rise to a Debye-Scherrer pattern together with a Laue pattern from the diamond.

Patterns of one of the two high-pressure modifications of calcite have been obtained and are under study. Aragonite shows no change at 24,000 kg/cm². It is suggested that some high-pressure polymorphism, although apparently completely reversible, with a definite volume change is actually between metastable modifications involving minor geometrical changes, the thermodynamically stable phase appearing only at higher temperatures where an otherwise difficult transformation may take place. This is especially true for structures involving complex ions such as carbonates and silicates. A thermodynamic argument confirms this for $CaCO_3$. Bridgman's two high-pressure modifications of calcite are both unstable with respect to aragonite. Neither calcite II nor calcite III will be found along the geothermal gradient although either might appear as the stable form in other carbonates, where the aragonite structure is suppressed by cation size.

LATE PLEISTOCENE PHENOMENA IN EAST-CENTRAL NEWFOUNDLAND*

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An area of approximately 400 square miles of low-relief terrain surrounding Meta Pond (Lat. 48°05′, Long. 54°50′) in east-central Newfoundland contains a large number of small morainal lakes, many of which are oriented roughly northeast. This region is surrounded on north, east, and south by an esker belt 20 to 30 miles wide that grades seaward into a broad belt of outwash plains and valley fills. More than 50 eskers have been recognized, all of which radiate seaward roughly paralleling the directions of glacial striae in the region. Northwest of Meta Pond eskers are noticeably absent, and the land there is strongly fluted in a southeast direction and contains large areas of bog.

More than a dozen seaward-trending stream valleys outside the esker belt contain outwash gravels and sands. Elevated deltaic deposits occur at the mouths of some of these valleys, the tops of which are at about 100 feet in Bonavista Bay and 65 feet in Fortune Bay and Bay d'Espoir.

Evidence of an ice advance beyond the region of outwash deposits before final retreat is supplied by marker erratics, striae, and stoss-and-lee forms on Bonavista, Burin, and Hermitage peninsulas.

Former outlets to Gander Lake and Gambo Pond have been recognized; that of Gander Lake is east into Bonavista Bay at Gambo, that of Gambo Pond east into Alexander Bay. Both lakes now drain north.

PRELIMINARY RESULTS OF THREE-DIMENSIONAL PACKING ANALYSIS

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Packing analysis recently completed seems to suggest that, in a sample of Pottsville sandstone from which three mutually orthogonal thin sections had been prepared (one of which was the bedding plane), packing might be considered a true vector property of a sediment.

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Average packing values obtained in different directions within a thin section give significantly different results. No significant differences were evidenced among thin sections. Utilizing the maximum and minimum packing estimates within thin sections as traces of planes, planes of maximum and minimum packing were constructed. The latter suggests tension forces, the former compressive. These preliminary results suggest an association between the textural property packing and the forces which have acted upon the sediment from initial deposition (compaction) to the present (tectonic, for example). Structural features such as jointing and fracturing may also be manifestations of planes of maximum and minimum packing. Further studies in the Appalachians are being undertaken to test these hypotheses.

RADIOCARBON-BASED PLEISTOCENE CORRELATIONS AND WORLDWIDE CLIMATIC CHANGE

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Radiocarbon data permit reassessment of the concept of worldwide, contemporaneous climatic history. South-central Alaska and Midwest glacial chronologies are correlated with a European sequence as follows: Eklutna-Illinoian-Saale (between 130,000 and 85,000*); Knik-"X"-Warthe (to 45,000*); Naptowne-Wisconsin-Fourth glaciation (to 3500*), with substages pro-Moosehorn-Farmdale, Iowan-Brandenberg, Frankfurt-Posen (to 17,000*), Moosehorn-Tazewell-Pomeranian (to 13,500*), Killey-Cary-Scanian (to 10,500*), Skilak-Mankato-Fennoscandian (to 7000*), Tanya-Cochrane-Ragunda Pause (to 3500*); and Alaskan—"little ice age"—(?) (after 3500*). These dated boundaries, marking culminations of interglacials and interstadials at intervals of 40,000 to 45,000 and 3000 to 4000 years, are derived from radiocarbon, varve (Degeer), depth of leaching (Kay), and astronomic ("Obliquity Cycle") calculations.

These correlations satisfy parallel sequence and indicate apparent contemporaneity of climatic trends throughout the Northern Hemisphere. However, local factors determined major differences in glacial intensity and age of maximum extent. Greatest extent of Naptowne, Fourth Glaciation, and Wisconsin glaciers was respectively 40, 800, and 1500 miles from ice-cap centers, and was reached at 16,500* in Illinois (Tazewell) and in Alaska (Moosehorn); 20,000* in Iowa (Iowan); and probably before 22,000* in Germany (Brandenberg). The suggested 41,000 year "Obliquity Cycle" climatic control for glacial stages involves a theoretical lag between Hemispheres of about 5000 years for Wisconsin age maxima. This is less than the indicated Northern Hemisphere regional lags and underscores the fact that more critical geoclimatic data is necessary before the postulated climatic lag between North and South hemispheres can be discounted.

POLYMORPHISM IN THE FELDSPARS AT HIGH TEMPERATURE AND PRESSURES

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Various feldspars have been examined at high temperatures and pressures, and polymorphic transitions have been demonstrated. Albite feldspar readily breaks down to jadeite + quartz or at higher pressure jadeite + coesite. The reaction of albite to jadeite + quartz takes place at 600° and 7 kilobars pressure and at 900° and 15½ kilobars pressure. Napheline + albite together enter into solid-solution relations with each other and react to form jadeite at pressures ranging from 11 kilobars at approximately 600° to 12 kilobars at 900°. Both orthoclase feldspar and anorthite compressed at 600° and 20,000 kilobars underwent transitions to new dense phases not yet identified. The position of the transition boundary of both these feldspars is under investigation. Basalt glass has also been investigated at high pressure and temperatures. It readily crystallizes to a feldspar-

* Approximate B. C. dates

rich mineral assemblage at temperatures of 800° and 1,000° and pressures of 10,000 bars to 15,000 bars, respectively. However, at pressures greater than these, the basalt glass readily crystallizes, but feldspar is absent from the phase assemblage. Presumably the crystallization is to an eclogitic mineral assemblage, but the individual minerals which make up the assemblage have not been identified with certainty.

LIMESTONE CONGLOMERATES OF THE COW HEAD AREA, WESTERN NEWFOUNDLAND

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Seashore exposures in the Cow Head area, Newfoundland, display a succession of limestone conglomerates interbedded with shales and limestones. Conglomerate layers range in thickness from 1 foot to more than 200 feet. The material consists of flat angular chips or moderately rounded boulders of fine-grained gray or white limestone. Fossiliferous boulders from any one layer yield trilobites of the same limited age.

Boulders from the lowest conglomerate at Broom Point contain *Kootenia*, *Zacanthoides*, *Orriella*, *Agraulos*, and *Peronopsis*. Succeeding bedded limestone yields *Meneviella* and *Tomagnostus*. A boulder in the overlying conglomerate also contained *Meneviella* and *Tomagnostus*.

Upper Cambrian conglomerates at Cow Head yield younger trilobites in successive layers: *Tricrepicephalus* in the lower; then *Taenicephalus*; followed by *Ctenopyge*, *Rasettia*, and *Keithiella*. Above are beds with *Staurograptus* and *Dictyonema*, overlain by conglomerates with early Ordovician trilobites.

Successively higher black shales contain graptolites of the Levis shale zones, and interbedded conglomerates yield successively younger Ordovician trilobites. Shale with *Trigonograptus* and *Isograptus* immediately underlies the highest conglomerate which yields *Nileus*, *Bathyurellus*, *Remopleurides*, and *Ectenonotus*. The thick limestone conglomerates at Lower Head include enormous boulders, one of which contains many of the trilobites described by Billings as from "Cow Head". This layer is underlain by black shale with *Isograptus*.

The "Cow Head breccia", therefore, is not a single formation but a succession of conglomerates and intervening beds ranging in age from Middle Cambrian to Middle Ordovician. The boulders of any conglomerate are approximately the same age as the immediately underlying strata.

PRELIMINARY OBSERVATIONS OF BANDING IN PEAT

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Present-day peat accumulations of the Southeastern United States are being studied to gain an insight on the origin and nature of some petrographic features detected in western Tertiary and Cretaceous coal beds. Field studies, supplemented by laboratory investigations, indicate that alternating dense and hydrous layers of peat might be responsible for widespread banding found in some coals.

A resistant surface crust of peat was observed in all areas examined. This uppermost layer maintains its coherence primarily through a mass of living and dead roots that bind together the organic debris. Immediately below the crust a watery peat layer consists mainly of highly comminuted debris. Roots may penetrate this layer but do not act as binding material. It is postulated that the lower layer may develop, at least in part, by attrition of the underside of the surface crust. Fluctuations

of water level in the swamp or marsh change the thickness of this water layer and may be responsible for some post-depositional sorting of inorganic detrital material.

Resistant layers in places were found beneath the crust intercalated with the watery peat layers. These layers resemble portions of a former crust, having a matted texture and abundant fine roots binding the peat mass.

Field studies suggest that in many instances the watery and resistant layers may not become compacted until peat deposition is culminated by a covering mantle of inorganic sediments.

COAL MICROSCOPY: TRANSMITTED AND REFLECTED LIGHT*

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The original objectives of this investigation were an examination of resin rodlets containing vesicles and a comparison of opaque-pitted rodlets with sclerotia of the type reported from Paleozoic coals of Europe. It was obvious after a brief examination of Illinois coal in both transmitted and reflected light that certain fundamental aspects of both methods of coal microscopy should be recorded. The objectives are then to report data concerning the resin rodlets and record observations related to transmitted and reflected light coal microscopy.

The writers agree with Teichmuller that both transmitted- and reflected-light methods of analysis can be used profitably in the examination of translucent and mixtures of translucent and opaque coal components. This became apparent in the examination of resin rodlets with vesicles in which the transmitted light varied from normal red to progressively opaque. Either method may be decidedly more advantageous than the other for special samples or studies.

Discrepancies between the two methods of analysis are attributed by Teichmuller to the fact that the coal components are obliquely oriented; this is observed *in toto* in transmitted light, but not in reflected light, because only surface structures are observed since there is virtually no light penetration of the coal. Ultra-thin polished sections reflect light as well as thicker ones. Therefore, discrepancies in analyses of these two methods can be maintained at a minimum by use of this type of polished thin section.

RELATION OF LEAD AND SULFUR ISOTOPES TO THE ORIGIN OF MISSISSIPPI VALLEY ORES

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Lead isotope abundance measurements on more than 100 galena samples from the Southeast Missouri ore deposits show that solutions progress from more to less radiogenic in time. The variations in the S^{32}/S^{34} ratio are small and are apparently related in no simple way to the Pb^{206}/Pb^{204} ratio and the direction of ore fluids. The data can probably best be interpreted to indicate inhomogeneous extraction from a granitic source in the shallow crust, although some of the sulfur may have been picked up en route. No evidence for isotopic fractionation due to transport or deposition was observed. A galena sample from the Precambrian basement in the lead belt area falls on the Pb^{207} vs. Pb^{206} curve. This is strong evidence against ore formation from laterally moving meteoric water. The relative constancy of the Pb^{206}/Pb^{208} ratios throughout the district show that the source of the lead fluids was granitic, i.e., high in both U/Pb and Th/Pb. Such studies may make it possible to determine the history and direction of mineralization of an area.

* Published with permission of the Chief, Illinois Geological Survey

EFFECT OF THE OCEAN ON PERMAFROST TEMPERATURES

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In high-latitude regions the large difference between the mean annual temperature at the surface of the ground and that in the unfrozen bottom sediments beneath bodies of water has a marked effect on ground temperatures to depths of several hundred feet. The effect is of particular interest near the edge of the ocean where it depends upon the magnitude of the temperature difference between the land surface and ocean bottom, the thermal properties and moisture content of the sediments, and past changes in climate and shore-line configuration. Theoretical considerations suggest that, except where there are transgressing shore lines, permafrost at depths greater than about 100 feet beneath the ocean bottom is not to be expected more than a mile offshore. Similar considerations indicate that coastal geothermal installations in the Arctic and Antarctic can give information regarding post-Pleistocene shore-line changes.

The geothermal effects of bodies of water offer a possible explanation for the anomalously large outward earth-heat flow recently reported by Misener for Resolute Bay, Cornwallis Island, N.W.T., Canada.

MISSISSIPPIAN STRATIGRAPHY IN EASTERN NEVADA

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The following lithologic units are widely distributed in eastern Nevada: Diamond Peak and Scotty Wash quartzites—sandstone, shale, and conglomerate; White Pine shale—sandy unit, black fissile unit, calcareous silty unit; and Joana limestone—medium-bedded unit, thin-bedded unit, thick-bedded flinty unit (descending order). The entire sequence thickens from approximately 900 feet around Glendale to 2500+ feet at Sunnyside, from there thins to 850 feet at Ely, thence thickens to 5000+ feet at Eureka. This suggests an Ely positive area in the Mississippian miogeosyncline with a partially enclosed Sunnyside-Pioche basin to the southeast. The Diamond Peak lies entirely northwest of Ely, and the Scotty Wash occurs only in the Sunnyside-Pioche Basin. The sandy and calcareous, silty units of the White Pine are absent at Ely, and the latter is largely restricted to the Sunnyside-Pioche Basin. All three Joana units are prominent in the Sunnyside-Pioche Basin, but only the lowermost extends across the Ely positive area, thinning westward and disappearing at Eureka. A fourth, thin-bedded, nodular limestone unit intervenes between the thick-bedded, flinty Joana unit and Pilot shale north of Cherry Creek.

Stratigraphic relationships between Alamo and Glendale suggest the following physical correlations: basal Joana unit—Dawn, Anchor, and Bullion limestones; middle Joana unit—Arrowhead limestone; and upper Joana unit—Yellowpine limestone. South of Glendale post-Joana rocks are probably removed by pre-Bird Springs erosion.

The Pilot shale is absent at Duckwater and Lund, probably because of pre-Joana erosion.

DISTRIBUTION OF IONIUM AND SELECTED TRACE ELEMENTS IN DEEP-SEA SEDIMENTS

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A new technique, utilizing a gamma-ray scintillation spectrometer, is employed for the quick direct determination of ionium (thorium 230) in deep-sea sediments. Radium and thorium, in equilib-

rium with their decay products, and potassium are also simultaneously measured. The variations in the ionium content of the core material are compared with the abundances of Pb, Cr, Fe, Si, Ti, Na, Ni, Ca, Mn, and Sr as analyzed by spectrochemical methods. The mechanical properties of the sediment were also related to the ionium and trace-element content of the samples, and no consistent relationship was noted. Leaching with a strong saline solution produced no detectable changes in the ionium or trace-element concentration, other than the reduction of Sr in high Sr-content samples.

The ionium content of the cores is evaluated with reference to the utilization of the natural radioactive decay of this isotope in making age determinations and rate of deposition estimates on deep-sea sediments. In two long eastern Pacific Ocean cores, the ionium content decreased with depth until it reached a value representing equilibrium with the amount of uranium present. The depth of the uranium-ionium equilibrium in both cores falls between 30–40 cm. Superimposed on the general decrease of ionium with depth are variations which appear to have a positive correlation with the Ti-content fluctuations.

RAPID DISINTEGRATION OF ALLUVIAL-FAN MATERIAL NEAR AKLAVIK, NORTHWEST TERRITORIES

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Search for a new site for the town of Aklavik in the delta of the Mackenzie River, N.W.T., which the Canadian Government has decided to move, involved detailed site investigations of four prospective locations. One was on the gently sloping surface of an alluvial fan adjacent to the Richardson Mountains on the western rim of the Mackenzie Delta. Predictions from surficial evidence were invalidated when test drilling in the perennially frozen ground disclosed at least 40 feet of organic silt and no sand or gravel. Materials eroded from the adjacent mountain slopes include sandstone and shales of Cretaceous age. The intense frost action at this latitude (68°08′) causes rapid mechanical disintegration. Turbulent stream flow continues the accelerated weathering process which is still further aided by the annual growth of fast-growing grasses on the surface of the stream meanders. The short growing season leads to rapid decay of this grass cover, which, with the annual layers of stream-bed material, results in the organic silt instead of the more usual muskeg of the North.

HYDROTHERMAL ALTERATION OF THE TOPIA MINING DISTRICT, DURANGO, MEXICO

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At Topia, a silver district on the west slope of the Sierra Madre Occidental, three types of alteration are recognized in early Tertiary andesites: the regional propylitic, local propylitic, and quartz sericite. The regional and local propylitic types are green chlorite-rich rocks essentially similar, but of different age.

The regional type surrounding a granodiorite stock in the southwest part of the district is a widespread pervasive alteration in which three mineral assemblages were recognized and interpreted as an intensity zoning outward from the granodiorite. The assemblages, in order of decreasing intensity, are albite-chlorite-epidote; albite-chlorite-epidote-calcite; albite-chlorite-calcite.

The local type, characterized by an albite-chlorite-calcite assemblage, forms bands up to 25 m wide bordering every vein in fresh andesite beyond the regional zone. Chemical analyses indicate relative decrease in silica and Na_2O and relative increase in MgO, FeO, CO_2, and combined water.

The quartz-sericite type forms narrow (30–60 cm), gray, quartz-rich bands between the vein and propylitized andesite. Abundant silica, some K_2O, and S were added; other constituents de-

creased. This type is superimposed on local or regional propylitization and represents a more intense alteration related to vein mineralization.

Alteration and ore deposition were related to the same general period of hydrothermal activity. The regional propylitization is considered an early, barren type related to intrusive activity. Local propylitization and quartz-sericite alteration are related to a later, more intense phase of activity culminating in ore deposition along controlling fissures.

ENGINEERING-GEOLOGY PROBLEMS INVOLVING PLEISTOCENE DEPOSITS IN THE NORTHERN GREAT PLAINS*

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Much of the northern Great Plains is underlain by Pleistocene deposits. Some examples of engineering-geologic problems caused by these deposits in connection with planned construction work are given:

(1) Several thousand square miles of ground moraine in northwestern North Dakota was unsuitable for irrigation because of low permeability of the till and near absence of surface drainage. Planned dams, canals, and pumping stations were relocated to serve an alternate area.

(2) Studies of Pleistocene deposits at Tiber Dam in northwestern Montana showed that till at the site was excellent fill material for the dam, that near-by glacial gravel was usable for aggregate, and that a buried channel bypassing the dam presented no leakage problem because it was filled with nearly impermeable till.

(3) A building in Great Falls, Montana, failed because its foundations rested on highly plastic glacial-lake clay. The foundation of a newer, near-by building was extended a few feet deeper than originally planned so as to rest on firm bedrock. This design change was based on geologic maps and sections that showed the distribution and thickness of the lake clay.

These examples are deliberately chosen from among those in which the geology was known early enough to be put to practical use. As the Pleistocene geology of this area becomes better known through systematic mapping and through intensive studies of construction sites, such examples should be multiplied many-fold.

POTASSIUM-ARGON AGES FROM THE NEW YORK CITY AND SPRUCE PINE, NORTH CAROLINA AREAS

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New potassium-argon age determinations have been made on metamorphic and igneous rocks from two critical areas where the solution of the geologic history requires absolute ages. Detailed studies of different potassium minerals from the same pegmatite have helped define the relative retentivities of the minerals used in this age method.

Ages obtained on separated mica from the Manhattan schist and the Inwood marble suggest a post-Cambrian age for the final recrystallization of these rocks of the Manhattan prong. This is in contrast with the much older rocks of the New Jersey–New York Highlands where the Canada Hill gneiss appears older than 1.0 b.y. and pegmatite associated with the zinc ore body at Franklin is at least 1.1 b.y. old.

New measurements on metamorphic rocks of the Southern Appalachians confirm the Precambrian time for the main plastic deformation in the region and suggest that the Bakersville dike swarm was also metamorphosed prior to the intrusion of the relatively late (350 m.y.) Spruce Pine pegmatite swarm.

* Publication authorized by the Director, U. S. Geological Survey

UNCONFORMITY BETWEEN BELT SERIES AND ARCHEAN METAMORPHIC ROCKS

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The unconformity between the Belt Series and Archean Metamorphic rocks is exposed in sec. 31, T. 1 N., R. 3 W., Jefferson County, Montana, 6 miles southeast of Whitehall and 1 mile west of the Mayflower mine; the area is accessible by country roads.

Belt strata unconformably overlie Archean rocks and are overlain concordantly by Cambrian formations. Belt and Cambrian beds are faulted against early Tertiary volcanics. Archean rocks are exposed as five small inliers in Belt strata. Attitudes in Archean (N. 20°–65° E., 50° S.E.) and Belt (N. 50°–65° E., 50°–65° S.E.) rocks are similar. Two linear exposures, one of marble and one of schist, trend N. 30° E. for about half a mile on a ridge crest. At least 300 feet of relief exists between ridge crest and bordering gulches. Ridge slopes, eroded on Belt rocks, are steep. The east ridge faces the top of the Belt series.

This area apparently was a west-facing shore line when the local Belt sediments were deposited. Cliffs and steep slopes characterized this shore line developed on Archean rocks. The following field evidence supports this interpretation: (1) Archean rocks form the crests of hills, whose steep slopes (20°–25°) are underlain by Belt rocks; (2) relief of 300 feet on these hills indicates a very steep contact between Belt and Archean rocks; (3) Belt conglomerate, near the south corner of secs. 29 and 30 and west of the linear exposures, contain marble, schist, and gneiss boulders up to 6 feet in diameter; north and east of this area Belt strata are conglomeratic.

SODA-RICH IGNEOUS ROCKS OF HELL'S CANYON, IDAHO

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Hell's Canyon is part of the Grand Canyon of the Snake River where it divides Idaho and Oregon. West of Riggins, Idaho, the Snake River has cut and exposed the Permian Seven Devil volcanic rocks which are unconformably overlain by limestone and chloritic schist of the Lucile Series (Triassic). A small satellite of the Cretaceous Idaho batholith cuts the Seven Devil volcanic rocks.

The Seven Devil volcanic rocks are soda rich and contain albite and oligoclase. The volcanic rocks consist of dacite, sodaclase dacite, and andesite flows, tuffs, and breccias. The high-soda content of these rocks is of primary origin, probably resulting from the differentiation at depth of a trondhjemetic magma from a parent basalt. The soda-rich rocks are comparable to the soda-rich Permian Clover Creek greenstone of the Baker quadrangle in Oregon where keratophryes, quartz keratophyres, and meta-andesites are found.

The satellite of the Idaho batholith also reflects the soda-rich environment; it is composed of tonalite and sodaclase tonalite. These soda-rich rocks are identical to intrusions of eastern Oregon which have been classified as albite granites.

These similarities in the geology of Hell's Canyon and of eastern Oregon suggest that this part of western Idaho belongs in the geologic province covered by eastern Oregon.

CAUSE OF BRAIDING BY A GRADED RIVER

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South of Hailey, Idaho, the Wood River meanders in a forest for many miles, braids in a 3-mile segment where the valley floor is prairie, and returns to a meandering habit where the river re-enters a forest. The river is stable or slowly degrading in all three segments. The essential cause of the dras-

tic difference in channel characteristics in adjoining segments is a difference in bank resistance due to presence or absence of bank vegetation.

Sinuosity of rivers is determined by width/depth of their channels. Ribbon-candy meanders develop only because, in a channel of low width/depth, factors which inhibit growth of bends are outweighed by a self-accelerating interplay in a set of factors which causes continued outgrowth. With high width/depth, a balance is struck between opposed sets of factors when bends attain a low curvature. Sinuosity is inversely proportional to width/depth.

Incidence of channel islands is also controlled by width/depth. Channel-island index (length of channel islands/length of channel) varies systematically from zero for channels with low width/depth to more than 2 for channels with high width/depth.

Width/depth is itself determined by (1) erosional force applied to the banks, and (2) bank resistance; it varies directly with (1) and inversely with (2). Erosional force is proportional to transporting force and is determined by discharge and load. Bank resistance is determined by the nature of the bank-forming material plus a vegetation factor.

STRATIGRAPHY OF THE MIDDLE ORDOVICIAN PLATTEVILLE FORMATION IN THE VICINITY OF MINNEAPOLIS AND ST. PAUL

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The northernmost outlier of Platteville formation in Minnesota occurs in the Twin City area. In addition to having the thickest and longest continuous exposures of Platteville formation north of Fillmore County, Minnesota, the Twin City section may be subdivided into five units on a lithologic basis (in upward order above the Glenwood Shale):

(1) 14 inches of brownish to olive gray, very fine-grained, argillaceous, dolomitic limestone with phosphatic debris concentrated in the lower 6 inches and a corrosion surface near its top
(2) 13 feet of light- and medium-gray, sublithographic and microgranular, thin and crinkly bedded, shaly, dolomite-mottled limestone with a second corrosion surface at its top
(3) A single 6-foot bed of yellowish and greenish-gray, microgranular, finely and indistinctly laminated, argillaceous, dolomitic limestone with a thin bentonitic shale at the top
(4) 8 feet of light olive-gray, microgranular, thick-bedded dolomitic limestone terminated at the top by a third prominent corrosion surface
(5) 3 feet 6 inches of medium-dark-gray and pale-yellowish-brown, fine-grained, thin-bedded dolomitic limestone with a 3-inch bentonite present 2 feet below the top of the unit wherever it is protected by the overlying Decorah shale

All units undergo facies change from the Twin City area but are traceable eastward to the St. Croix River and a short distance into Wisconsin.

LIMITATIONS ON CALCULATIONS, RELATING p-t EQUILIBRIA TO THERMOCHEMICALLY DETERMINED PARAMETERS

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A complete calculation of the free energies of both solid and volatile phases (and thence the equilibrium) as a function of pressure and temperature has been carried out for the reaction $CaCO_3 \rightleftarrows CaO + CO_2$ to illustrate the precision required in available thermochemical data for such calculations. The actual magnitudes of the effect of pressures (up to 1400 bars) on the free energy of the solid phases has been calculated at a series of temperatures. Neglecting this factor can be justified in the range of most hydrothermal experimentation.

The recommended procedure uses: 1) The free energy of the volatile as a function of pressure and temperature (available for CO_2 and H_2O). 2) The heat capacities of the solid phases as a function of temperature. 3) The heats of formation of the phases involved. For reactions such as $MgCO_3 \rightleftarrows MgO + CO_2$; and $CaCO_3 \rightleftarrows CaO + CO_2$, agreement with experimental data is good. For reactions such as $MnCO_3 \rightleftarrows MnO + CO_2$; $2AlO{\cdot}OH$ (boehmite) $\rightleftarrows Al_2O_3 + H_2O$; $Mg(OH)_2 \rightleftarrows MgO + H_2O$ very large deviations (from the experimental values) are observed. The extreme precision necessary in the thermochemical data is illustrated. The magnitude of the errors in the extrapolation of experimental p-t data to very low or very high pressures by simplified procedures is calculated. When heat capacity data are available a procedure for extrapolation from one experimental p-t point is illustrated for the $Mg(OH)_2 \rightleftarrows MgO + H_2O$ reaction.

PALEOMAGNETISM OF CHEMICAL SEDIMENTS

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This is a report on new significant results of paleomagnetic studies of chemical sediments. Some of the rocks sampled consisted of large ellipsoidal, calcareous concretions from the Barnett shale (Mississippian). These concretions appeared to be syngenetic (or nearly so). Nine locations were sampled at outcrops of the Barnett on the northwest, north, northeast, and southeast sides of the Llano uplift in Central Texas.

The results from 60 measurements indicate the position of the South (not seeking) Magnetic Pole of Mississippian time to be at 39° N. Lat. and 124° E. Long. Eight measurements of a reversely magnetized limestone place the North Pole at 42° N. Lat. and 142° E. Long. These positions are in good agreement with Carboniferous pole locations by others.

Favorable evidence is presented to show the stability of magnetization of the Barnett in geological time.

Both the field evidence and the petrographic observations support the conclusion that the calcareous concretions are syngenetic. They are certainly formed as a result of chemical processes and they contain very little detrital matter. Therefore, the amount of detrital ferromagnetic minerals that could be present must be very small indeed and could hardly account for the magnetic intensities observed. This seems to be excellent evidence that the ferromagnetic minerals are formed through chemical processes and probably acquire their remanent magnetism during these processes. This we feel to be a significant conclusion.

URANIUM-BEARING COAL IN THE RED DESERT, WYOMING

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Uranium-bearing coal underlies approximately 300 square miles of the Red Desert, in the central part of the Great Divide Basin, Wyoming. The coal-bearing rocks were cyclically deposited in swamps marginal to lakes formed in Green River time. The coal sequence, about 1200 feet thick and of early Eocene age, grades into coarse-grained fluviatile arkose of the Wasatch formation to the northeast and is interbedded with organic lacustrine shale of the Green River formation to the southwest.

Local high concentrations of uranium occur in carbonaceous beds unconformably overlain by gravels of possible Miocene age, as at Creston Ridge where the uppermost coal bed contains as much as 0.051 per cent uranium near the top of the bed, whereas a coal bed 40 feet lower contains less than 0.001 per cent.

Widespread but lower concentrations of uranium in the coal, averaging about 0.003 per cent, are apparently related to the permeability of the rocks enclosing the coal beds. The uranium content of the coal beds increases toward the northeast as the lithofacies change and become coarser-grained

and more permeable. In the cyclically deposited sequence several successive coal beds are enriched in uranium adjacent to beds of coarse-grained, permeable sandstone.

The distribution pattern suggests that the uranium was derived from overlying rocks and carried downward and laterally by ground water via the sandstone aquifers and deposited in the carbonaceous rocks.

Gallium, germanium, iron, molybdenum, lead, vanadium, and the rare earths have distribution parallel to the uranium and may have been similarly emplaced.

OBSERVATION DIFFERENCES IN DRAINAGE-NETWORK ANALYSIS

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To determine the applicability of quantitative geomorphic analysis to drainage basins in mountains having a complex erosional history and numerous cliffs and waterfalls, field studies were made during 1955 and 1956 in the chaparral-covered San Dimas Experimental Forest of the San Gabriel Mountains, California. To test reproducibility of field data, a matter of fundamental importance about which little is known in quantitative geomorphology, duplicate field surveys and analyses were made of two basins by two independent investigators. At the outset the same criteria were agreed upon by both investigators for field identification of features to be measured, although difficulty was encountered in defining a stream channel.

Channels located and measured in the field and on aerial photographs were plotted on large-scale base maps. Analyses of one basin studied intensively by both investigators agreed remarkably well. No significant differences were found between the numbers of channel segments, bifurcation ratios, length distributions, length ratios, and distribution of basin areas by order. A second basin was studied less intensively by the second investigator, whose omission of some channels decreased the numbers of channel segments and modified the distributions of channel lengths and basin areas; otherwise his results agreed well with those of the first investigator.

Consistent agreement between sets of data obtained independently thus indicates that quantitative analysis is applicable to the complex San Gabriel mountain watersheds, without serious variability introduced by differences in operator judgment. Even better agreement would be expected in watersheds of simple geomorphic history.

CONTROL OF TOPOGRAPHIC TEXTURE BY CLIMATE, LITHOLOGY, AND SURFACE PROPERTIES

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Topographic texture is measured by drainage density (D) and channel frequency (F). Data from 23 western watersheds, in arid to subhumid climates, indicate that clastic, granitic, and acid-volcanic rocks produce the same drainage density, shale and schist produce high density, and limestone produces low density under similar conditions. Quantity D is correlated inversely with Thornthwaite's precipitation-effectiveness (P-E) index ($r = -.94$), soil-infiltration capacity ($r = -.79$), and wet-soil strength ($r = -.43$), and is correlated directly with runoff intensity ($r = .66$) and per cent bare area ($r = .90$). No significant correlations were found between texture and average rainfall intensity or surface roughness. Although theoretically independent, F varies closely with D^2. Linear plots were obtained by power and exponential functions.

In the samples used, 93 per cent of the total variation in D was explained statistically by climatic and surface properties alone: P-E index, infiltration capacity, and runoff intensity were most important. Because of high intercorrelations, additional consideration of any single surface property, when P-E index is already considered, does not significantly increase the explained variation in D. Surface properties thus control texture but are themselves controlled by climate, lithology, and history.

unless altered by accidental conditions. Accidents cause changes in surface properties and produce new values of D or F, not expected from consideration of climate and lithology alone. In mature topography, changes in texture occur rapidly.

SEISMIC EVIDENCE FOR BASEMENT UPLIFT IN THE GEORGIA-SOUTH CAROLINA COASTAL PLAIN

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Reversed seismic-refraction measurements in the Georgia-South Carolina coastal region suggest the existence of a basement topographic high. While the full extent and width of this feature has not been delineated, its presence is indicated by abnormally shallow depths to basement and in part by westward dips of the basement surface. On the basis of available information it would appear to strike parallel to the coast line.

While it is not known whether this feature is a structural uplift or buried ridge, it appears to form an eastern boundary for the Southeast Georgia basin.

A plot of earthquake epicenters for the region depicts seismic activity along a line striking approximately north-northeast from Savannah, Georgia. This also is the approximate strike of the basement feature mapped and suggests that the two may be genetically related.

TREND MAPPING CONTEMPORARY SEDIMENTARY ENVIRONMENTS

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The problem of defining and analyzing contemporary environments of sedimentation is approached from the point of view of mapping "trend surfaces." The "trend surface" is a surface of best fit to points distributed over a sampled field region. In this way an objective, continuous pattern which avoids unrealistic definite boundaries can be established for each measurable property of an environment of sedimentation. Examples of measurable properties in this context are average sediment size, sediment sorting, and shape. Patterns may then be grouped into classes to characterize various environments.

A second, closely related problem is to examine measurable properties which will pass through the time-diagenetic zone unchanged in a statistical sense, in order to ascertain how much can be inferred about strictly contemporary properties. Properties of this kind are severely restricted in number. An example of such a property is average sediment size. Examples of properties which do not pass through the time-diagenetic zone unchanged include most chemical properties.

Application is made to the near-shore area off La Jolla, California, and good agreement is found between local wave and current systems, and sorting. Further application is made to a dune-margin, beach, and near-shore area at the southern end of Lake Michigan. Field work is now under way to extend the types of environments under study.

ACTION OF HOT WATER ON SOME CARBONATES

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Pure H_2O, freed from CO_2 by passing over a suitable ion-exchange resin, is passed over calcite, magnesite, or dolomite contained in a stainless steel tube heated in a furnace. The pressure is held at about 3000 psi, above the vapor pressure of water at the highest temperature used in these experiments, thus ensuring that there was no steam, only liquid water. The solubility of calcite at 25° is about 20 ppm and changes little up to about 150°, where it begins to fall uniformly to about 7 ppm at 350°. The solubility of magnesite increases with temperatures up to about 150° but above

that temperature decreases rapidly. *X*-ray studies showed that below 150° magnesite was not altered, but above 150° it was decomposed, with formation of brucite, $Mg(OH)_2$, and liberation of carbon dioxide. Dolomite also is decomposed by water above 200°, but the exact temperature at which decomposition begins has not been determined. At and below 209° *x*-rays show the dolomite pattern, above this temperature brucite and calcite. At 179° analysis shows that the solution contains some free carbon dioxide, and possibly the decomposition began at that temperature, but below 209° the rate was too small for the brucite to show in the *x*-ray pattern. It is planned to make some long runs to test this point. These experiments are being continued, and it is planned to include siderite and to use water containing a small proportion of CO_2.

HYDROTHERMAL STUDY OF SOME HYDROUS COPPER SILICATES

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In a hydrothermal study of the system $CuO—SiO_2—H_2O$, using synthetic "gel" preparations and the minerals dioptase and chrysocolla as starting materials, decomposition temperatures for dioptase and plancheite have been determined. Although none of the minerals was prepared from synthetic mixtures, under 20,000 psi water pressure dioptase, $CuSiO_3 \cdot H_2O$, from Altyn Tübe, Siberia, dehydrated to plancheite, $3CuSiO_3 \cdot H_2O$, at about 315°C, which in turn yielded tenorite, (CuO) + silica, at about 400°C.

Natural chrysocolla went from a blue material amorphous to *x*-rays to either CuO or Cu_2O and SiO_2 at approximately 200°C. Both *x*-ray and electron-diffraction studies of chrysocolla failed to yield unambiguous indications of its relation to the montmorillonoid group.

These decomposition data provide a limit for the conditions of formation of the natural minerals involved.

CRYSTALLOGRAPHY AND X-RAY MEASUREMENTS OF HOWLITE FROM CALIFORNIA

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Crystals of howlite, $H_5Ca_2SiB_5O_{14}$, found encrusting massive material from the Sterling borax mine, have been measured on the goniometer and studied by *x*-ray methods. The crystals, up to 1 mm across, are tabular and usually attached at one end of the symmetry axis. They are monoclinic, with {100} dominant, {001} and {011} well developed on all crystals. Occasionally orthodomes, such as {201} or {104?}, are present as narrow modifying faces. Morphologic elements are as follows: a:b:c = 1.47:1:0.965. Beta 105° 10′.

X-ray examination confirms the monoclinic symmetry, with systematic extinctions giving class $P2_1/c$ and elements in reasonable agreement with the morphological values. Rotation, and equator, first- and second-layer line photographs about *b* and *c* give the following cell dimensions: a_0 = 12.93Å, b_0 = 9.34Å, c_0 = 8.60Å, beta 104° 50′. All powder photograph lines can be readily indexed.

STRUCTURE OF (O)—H—O—H UNITS ASSOCIATED WITH KAOLINITE DEDUCED FROM INFRARED VIBRATIONAL SPECTRA*

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A structural scheme of (O)—H—O—H units associated with kaolinite was deduced from the infrared vibrational spectra. Calculated vibrational frequencies in wave numbers, ν, corresponding to a

* Released for publication by the Cities Service Research and Development Company

structural model were obtained by the *polynominal* method, expanded from the secular equation of small amplitude molecular vibrations,

$$| GF - E\lambda | = 0$$

where G represents the matrix of inverse kinetic energy elements of the mass and geometry of the molecule, F represents the stretching, bending, and torsional force constants, E represents the unit matrix, and where the roots $\lambda_i = 2\pi c\nu_i^2$. The agreement between the values of two observed and calculated fundamental frequency bands in the kaolinite spectra 3690.0 cm^{-1}, 3619.3 cm^{-1}, and 3690.9 cm^{-1}, 3619.4 cm^{-1}, respectively, indicates that one end of the molecule is O—H $\cdots$ O bonded and that the other end of the molecule is in the state of small-angle torsional oscillation. The equilibrium H—O—H is the tetrahedral angle, 109°28′. These spectral features are related to (O)—H—O—H units adsorbed on kaolinite crystal surfaces or to the interaction of structural OH groups in the kaolinite lattice. With these structural features it is possible to obtain vibrational modes corresponding to the two observed frequencies. Thus the structure is consistent with the spectra, however, it may not be unique.

RECENT SEDIMENTS IN THE GULF OF MEXICO—SABINE-HIGH ISLAND AREA

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Examination of 7000 samples collected from an area of 1000 square miles in the vicinity of Sabine and Heald Banks in the Gulf of Mexico indicates that the three principal types of sediments are sand, shell debris, and clay muds. Using simple field techniques, each type was subdivided, and a total of 10 lithologic types was mapped. The sands are clean, fine-grained, and very well sorted. Shell debris is composed of whole and comminuted shells of benthonic organisms. The fauna represented by the shells is a molluscan fauna made up predominantly of pelecypod shells. The clean sand bodies are found along the beach and on the banks; clay mud occurs near shore, and the shell debris occurs as patches on the sides of the banks.

Topography appears to be the greatest factor in determining the type of terrigenous sediment deposited. The factors controlling the distribution of shell debris are unknown.

The Recent sediments are underlain by the Beaumont clay of Pleistocene age, and the contact between the two formations is sharp. The upper few feet of the Beaumont clay is oxidized and contains bore holes or desiccation cracks and calcium carbonate nodules. This lithologic evidence indicates that a period of weathering or erosion, probably subaerial, preceded the deposition of the Recent sediments in this area.

FOLIATED STRUCTURES IN GLACIER ICE

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Mapping and thin-section study of foliated structures developed in "cold" glacier ice in northern Greenland have revealed a wide range of both tension and shear structures. These structures have been observed in outlet glaciers with flow rates as high as 8 feet per day and in "ramp" areas where flow rates are a fraction of an inch to a few inches per day.

The normal foliation consists of alternating bands of white, bubbly ice and clear, blue ice and is well developed in areas of low shear strain. Abnormally thick blue bands, some up to 20 feet, are present in some areas. These are commonly parallel to the normal foliation but are locally discordant. A "yellow" foliation, consisting of unequally distributed, finely divided debris, is common in areas where individual shears extend to depths within the glacier. Debris bands are common along major shears that extend to near the base of the ice. "Relict" banding appears prominently on aerial photographs but is extremely difficult to trace on the ground. It invariably crosscuts the

local foliation and appears to be a relict structure, perhaps a relict foliation, inherited from a different flow pattern in an upstream area of the glacier.

Tension features include cracks, crevasses, and ice dikes. These invariably crosscut the foliation at a high angle.

ISOSTATIC COMPENSATION FOR THE SIERRA NEVADA, CALIFORNIA

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During the summers of 1951, 1952, and 1956, about 1500 gravity stations were occupied in a 13,000-square-mile area of the Sierra Nevada, extending 120 miles north and south of the Mt. Whitney region. Complete Bouguer anomaly values range from −20 mgal at the western edge of the Sierra to a minimum of −250 mgal just west of the Sierra crest, a distance of only 65 miles. Other studies show that, farther eastward, a positive regional gradient of 1 mgal per mile continues at least as far as Death Valley. The form of this west-to-east Bouguer anomaly profile persists all along the strike of the Sierra; the maximum anomaly relief of 230 mgal is midway between Sequoia and Yosemite national parks. The anomaly relief drops off much more rapidly to the south than to the north; Bouguer anomaly values in the Bakersfield-Inyokern profile range from −40 mgal to −140 mgal, so the anomaly relief is only 100 mgal.

Isostatic anomalies corrected for local geologic effects are very close to zero at the western edge of the Sierra Nevada. The central and eastern Sierra regions are overcompensated by 40–50 mgal, suggesting that current uplift along the Sierra Nevada fault zone may be caused by isostatic forces. However, there is no local isostatic response to the 10,000-foot eastern scarp. Gravity determinations of the thickness of the earth's crust are in general agreement with seismological work in the Sierra Nevada by Byerly, Gutenberg, and Press.

GRAVITY STUDY OF THE STRUCTURAL GEOLOGY OF OWENS AND LONG VALLEYS, CALIFORNIA

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A regional gravity survey of Owens and Long valleys, California, revealed strong negative gravity anomalies associated with great thicknesses of clastic rocks that accumulated in these valleys.

A steep, nearly linear gravity gradient defines a fault zone that forms the boundary between the Owens Valley block and the White-Inyo mountain block to the east. Against this fault about 6000 feet of rocks of Cenozoic age is in fault contact with the older rocks. The western boundary of the Owens Valley block is in most places an irregular series of faults that are some distance east of the Sierra Nevada front; in general these faults are buried under alluvium. In Long Valley a great northeasterly trending fault near Lake Crowley was found, against which about 12,000 feet of rocks of Cenozoic age is in fault contact with the crystalline rocks to the east. This fault has no physiographic expression and is flanked by a broad pediment which lies to the west of the Benton Range. The fault forms a part of an elliptical fault system that bounds the Long Valley block. The faulting along the eastern front of the Sierra Nevada, with its profound physiographic expression, was followed by accumulation of a relatively thin section of alluvial-fan materials at the base of the mountains.

Prolonged, continuous, or repeated faulting accompanied the subsidence of the Owens Valley and Long Valley blocks to bedrock elevations of about 2000–5000 feet below sea level. A period of quiescence seemingly followed subsidence.

BURIED PRE-MODERN EROSIONAL SURFACE IN THE GEORGIA PIEDMONT

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Common but little-noted features in the Georgia Piedmont are lines and lenses of buried stones overlain by structureless soils. Many of the characteristics of the stone layers, such as roundness, lithologic types, and position relative to super- and subjacent materials, indicate that they formed as surface veneers and gully lag deposits. The past condition most likely to produce such an accumulation would be one of aggravated erosion similar in many aspects to that which has accompanied man's present occupancy of the southeast. Such an erosional condition in the past has climatic implications which may well be related to abnormal runoff and vegetative conditions during the Pleistocene. The wide occurrence of this buried erosion surface noted in hundreds of exposures further suggests that the concept of Piedmont residual soils is probably erroneous and that, in reality, a large percentage of surficial soils is undoubtedly colluvial.

REBOUND IN THE BEARPAW SHALE

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The Bearpaw formation (Upper Cretaceous) which occurs over large areas of Western Canada presents difficult problems in connection with engineering works. These clay shales were consolidated under high pressures, but the load has been removed. A rebound has occurred which is a maximum at the shale surface and decreases with depth. The total rebound is made up of elastic rebound which occurred immediately upon removal of load and a time rebound which is still occurring slowly and involves a softening of the material.

The characteristics of the shale and the depth of the rebound zone are being studied by soil-mechanics methods. Routine tests include water content and density and Atterberg limits; the water content is the best indicator of the consistency. The results of laboratory strength tests do not correlate well with observed field behavior, and this suggests that observations of existing slopes will supply more reliable strength data for long-time stability studies. Field investigations involve piezometric measurements and observations of slides, particularly creep. The softened surface zone is unstable, and slides have occurred on gentle slopes. Slickensides are common in this zone, but their intensity appears to decrease with depth. The underlying shale is firm and stable.

In addition to rebound resulting from geological unloading there is also rebound caused by local excavations for structures. Observations are being made on light concrete structures to correlate predictions from laboratory swelling tests with observed heave.

AGE STUDY OF A TEKTITE

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A Philippine Islands tektite was analyzed mass spectrometrically for K, Rb, and Sr. It contains 19,400 ± 500 ppm K; 104 ± 3 ppm Rb; and 161 ± 3 ppm Sr. Isotopic composition of the tektite Sr is: $84/88 = 0.0069 \pm 0.0002$; $86/88 = 0.1190 \pm 0.0005$; $87/86 = 0.731 \pm 0.003$. Assuming an original 87/86 ratio of 0.711, corresponding to an initial ^{87}Sr relative abundance of 7.00%, a minimum age of 750×10^6 years is calculated for the tektite. Terrestrial volcanic glasses (obsidians) older than Mesozoic are rare or unknown. It is tentatively concluded that the great age excludes the tektite from a terrestrial origin, for under terrestrial conditions a glass of tektite composition would be expected to devitrify in so great a time. To be of terrestrial origin the tektites would have to have

been melted from a pre-existing terrestrial rock, within the last 100 or 200 million years. It is proposed that tektites from all known localities be analyzed. If the 87/86 ratios are identical, in correspondence to their Sr/Rb ratios, then an extra-terrestrial origin will be proven.

ORIGIN AND AGE OF OZARK PLATEAU SURFACES IN NORTHWEST ARKANSAS

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Salem, Springfield, and Boston Mountain plateaus form three steplike surfaces of the Ozark Highlands that slope northeastward and gently truncate southwest-dipping Paleozoic strata. The plateaus are separated by two escarpments 400 and 800 feet high and have been deeply dissected. There are erosion remnants on all the surfaces including Boston Mountain Plateau. Four periods of dissection and three periods of planation are recognized. These are not rejuvenated peneplanes and monadnocks, but were eroded in place by alternate periods of stream entrenchment, providing the escarpments and periods of escarpment retreat (pedimentation), forming the plateau surfaces.

Valley entrenchment operates under humid conditions because streams progressively increase in volume from head to mouth and greatly increase competence and capacity. At the same time introduced load is minimal because of the protective influence of plant cover over interstream areas. Thus overloading cannot take place.

Escarpment retreat proceeds under arid conditions because streams are supplied principally by surface runoff during and directly after rainfall. Quantities of sediment are introduced into streams due to paucity of plant cover; volume increases only as long as rainfall continues and diminishes thereafter due to evaporation and infiltration. The static stream channel thus serves as a base level of erosion.

Humid-arid alternations of glacial-interglacial stages of Pleistocene time are known to have occurred. These seem to have been of proper number and sufficient magnitude to account for the Ozark escarpments and "pediplanes," landforms long recognized, separately, as belonging respectively to humid and arid regions.

EVOLUTION OF CORROSION ZONES IN LIMESTONE AND DOLOMITE

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In a 180-foot sequence of Middle Ordovician dolomite exposed in quarries of east-central Wisconsin, at least 20 black, pyritic "corrosion zones" have been recorded.

Marked differences between individual corrosion zones are believed to indicate different stages in an evolutionary sequence. Rather faint, irregular surfaces may represent an initial stage in which pyrite begins to accumulate in soft sediment slightly below the actual "bottom". As solution of the bottom progresses, the pyritic surface may be overtaken, and its uppermost irregularities may be bevelled off. The pyritic surface at this stage apparently forms a hard, relatively smooth, bottom crust over which sand grains and shells of organisms are moved with relative ease. Pyrite continues to accumulate beneath the crust, so that the original pyritic "surface" becomes a black, pyritic layer an inch or more in thickness. Further vigorous solution may perforate the crust and eventually reduce it to thin, irregular "slabs" or rounded "pebbles". Ultimately even these may disappear—the original pyritic zone being thus completely destroyed, while a new one may begin to form at a lower level.

Secondary recrystallization of the pyrite, and of adjacent calcite and dolomite, is a common additional cause of variation among corrosion zones in east-central Wisconsin.

LATE PRECAMBRIAN SEDIMENTS OF SOUTHEASTERN BRITISH COLUMBIA AND SOUTHWESTERN ALBERTA

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The extent and correlation of the Late Precambrian Purcell and Windermere systems of the region are briefly considered. The nature and distribution of the earlier Purcell System indicate variable conditions of deposition both horizontally and vertically, with no consistent indication of source area. Probably, however, these sediments were derived from the Canadian Shield to the east and north.

The distribution and lithology of the later Windermere and Lower Cambrian sediments show a consistent pattern of deposition in a miogeosyncline in the eastern Purcell Mountains and Rocky Mountains, and in a eugeosyncline in the western Purcell, Selkirk, and possibly the Monashee Mountains to the west. All these sediments were derived from the earlier deformed Purcell Terrain to the southeast and the Canadian Shield to the northeast and north.

STRATIGRAPHY AND PETROGRAPHY OF THE IRON FORMATION AT ROSS MOUNTAIN, QUEBEC*

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Ross Mountain lies in the northern part of the Upper Precambrian Quebec-Labrador geosyncline at Lat. 57°25′ and Long. 70°00′ about 5 miles from the western granite border of the geosyncline. The sedimentary beds on Ross Mountain strike north to slightly west of north and dip about 30°E. Metamorphism is insignificant.

From the base upward the stratigraphic section includes 50 feet of shaly magnetite chert, 100 feet of interbedded lenticular chert and cherty siderite, and 125 feet of bedded to massive cherty quartzite.

The shaly magnetite chert consists of magnetite, chert, minnesotaite, chamosite(?), greenalite(?), and minor stilpnomelane. The interbedded lenticular chert and cherty siderite consists of siderite, chert, and minor magnetite, whereas the cherty quartzite has replaced siderite. The minerals occur as granules, oölites, and as interlocking grains in thin laminae.

The minerals formed by primary chemical precipitation or, in the case of some chert and the minnesotaite and stilpnomelane, during early authigenesis. Land-derived detrital particles are absent. The type and variation of the mineralogy of the beds can be explained by physicochemical data governing the stability ranges of the various minerals.

COMPOSITIONS OF FELDSPARS IN SOME TWO-FELDSPAR GRANITES

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The feldspars from 60 specimens of two-feldspar granites from the eastern United States, South Dakota, and Texas were separated, highly purified, and analyzed by x-ray diffractometer. The potassium feldspars were homogenized and sanidinized hydrothermally, and their bulk compositions were obtained from the spacing of the $(\bar{2}01)$ plane (Bowen and Tuttle). The plagioclases were analyzed by the method of Tuttle and Bowen based on the change with composition of $2\theta(131)$–$2\theta(1\bar{3}1)$ in

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"low-temperature" natural plagioclases. Results obtained by this method are compared with those based on variation of the α index.

Potassium feldspars were nearly all triclinic. A sample from each granite specimen was heated at 1040°C for 6 months. The obliquity, or departure from monoclinic symmetry, was measured both before and after heating. All the samples were homogenized, and all but a few were completely transformed to monoclinic sanidine. Spectrographic analyses were made on four samples that were not sanidinized by the heat treatment and on one sample that was completely inverted.

The average An content of plagioclase differs markedly from mass to mass, but differences in Ab content of microcline were not significantly greater than might be expected in specimens from a single mass.

DISTRIBUTION OF ALPHA-EMITTING ELEMENTS IN THE VOLCANIC ROCKS OF MOUNT LASSEN, CALIFORNIA

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The distribution of alpha-emitting elements in the volcanic rocks of Mount Lassen, California, has been studied by the use of liquid nuclear emulsions applied directly to the surface of uncovered thin sections. In each section, counting of approximately 100 alpha tracks and identification of the minerals from which each track emanated permits calculation of the following ratio for each mineral in the rock:

$$\frac{\text{percentage of alpha tracks from mineral}}{\text{percentage of mineral in rock}}$$

Such ratios are approximately 1 for all minerals (commonly plagioclase, pyroxene, hornblende, and/or biotite) and the glassy phase in each rock. Thus, it appears that none of the identified phases are either enriched or impoverished in alpha-emitting elements.

It is believed that this apparently random distribution of radioactive material is a result of the very rapid cooling and solidification of the lavas. Presumably, slower crystallization would have reduced entrapment of the alpha-emitting elements in the plagioclase and ferromagnesian minerals and would have permitted greater concentration of these elements in late-crystallizing accessory minerals such as zircon and sphene, which were not found in the sections examined.

STUDIES IN THE SYSTEM $CaCO_3$—$MgCO_3$—$FeCO_3$. PART I: LIMITS OF SOLID SOLUTION ALONG THE BINARY JOIN, $CaCO_3$—$FeCO_3$

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Subsolidus phase relations in the system $CaCO_3$—$FeCO_3$ have been investigated at elevated temperatures by using small partial pressures of carbon monoxide to maintain the iron as Fe^{++}. A solvus (miscibility gap) between $CaCO_3$ and $FeCO_3$ has been located at temperatures between 350°C. and 550°C. At pressures of CO_2 high enough to prevent the dissociation of the carbonates, solid solutions containing up to 8 mole per cent siderite in calcite and 5 mole per cent calcite in siderite are stable at 400°C. At 500°C., the solvus passes through points at 14 mole per cent calcite and 5 mole per cent siderite. No ordering of Ca and Fe has been observed in either the calcite or siderite solid solutions. The iron analog of dolomite, ferrodolomite—$CaFe(CO_3)_2$, has not been synthesized, and it is probably not stable between 350°C. and 550°C. and below 60,000 lbs./in.^{2}

Preliminary work has been undertaken in the ternary system $CaCO_3$—$FeCO_3$—$MgCO_3$, and a tentative ternary diagram showing the limits of solid solution has been drawn.

MISSISSIPPIAN ROCKS IN EASTERN CALIFORNIA AND ADJACENT NEVADA

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Stratigraphic sections of Mississippian rocks between Mazourka Canyon, Inyo Range, California, on the northwest, and the Spring Mountains, Nevada, on the southeast show that Mississippian carbonate rocks underlying the cyclic limestone and clastic rocks of the Bird Spring formation thicken to the northwest from the southern Spring Mountains where they are 800± feet thick. Their maximum thickness, 1800± feet, is reached at Cottonwood Canyon approximately 8 miles west of Stovepipe Wells, Death Valley. The name "Monte Cristo limestone" is applied to this predominantly carbonate section, and three members, closely resembling but much thicker than the Dawn, Anchor, and Bullion members of the Goodsprings district, are distinguished. The Mississippian section in the Quartz Spring area, approximately 15 miles northwest of the Cottonwood Canyon locality, is remarkably different. Probably less than 1500 feet of Mississippian rock, including the 400± feet of the Mississippian? Rest Spring shale, is present. Approximately the lower half is predominantly limestone; the upper half is shale, siltstone, and sandstone. To the northwest in and near Mazourka Canyon, shale with some limestone, sandstone, and conglomerate at the base dominates the section underlying the Bird Spring formation and probably exceeds 2000 feet in thickness. It is suggested that the Quartz Spring area may have been part of a Mississippian high area separating predominantly clastic deposition to the northwest from predominantly carbonate deposition to the southeast.

NATURE OF OUR PRODUCT

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The ideal product of higher education is an individual who can learn anything he may need to know to lead a productive professional life and a useful life as a citizen without taking further courses. This should be the objective of the undergraduate program, allowing graduate training to be something which the student does for himself.

If a geology curriculum is to attain this objective it must do the following:

(1) Recognize and present the basic principles of geology in an orderly fashion. Geology is the science of the earth, a dynamic planet. The dynamic processes of the earth are gradation, volcanism, diastrophism, and life. The effects of these processes comprise a sequence of events which, properly interpreted, yields the geologic history of the planet or of some portion of it.

(2) Require mathematics through calculus and 1 year each of chemistry, physics, and biology plus advanced work in one of these.

(3) Include at least one summer field course designed for basic field instruction.

(4) Insure basic fundamentals of citizenship.

(5) Avoid undue emphasis on applied courses in geology, the other basic sciences, and engineering.

PORTION OF THE SYSTEM $CaO—SiO_2—H_2O$

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New data obtained on the compound Ca_2SiO_4 indicate a downward revision of the inversion temperature of γ-Ca_2SiO_4 to α'-Ca_2SiO_4 (bredigite) to about 750°C at atmospheric pressure and 675°C at 2000 psi water pressure. The bredigite on cooling to room temperature inverts to β-Ca_2SiO_4 (larnite) which is remarkably stable. This hydrothermal stabilization may account for the persistence of larnite in nature.

Hydrothermal studies of compositions ranging from Ca_3SiO_6 to $Ca_4Si_2O_7$ reveal the presence of new compounds at elevated temperatures. A new hydrated compound formed from Ca_3SiO_6, designated $C_4SH(X)$, appears to form solid solutions extending at low pressures nearly to Ca_2SiO_4, and a *p-t* curve determined for the reaction $C_4SH(X) \rightleftarrows \alpha'\text{-}Ca_2SiO_4 + CaO$ indicates a temperature ranging from 825°C at 2000 psi to 875°C at 15,000 psi. Afwillite is stable up to about 225°C at 15,000 psi. Anhydrous Ca_2SiO_4 is stable at a pressure of 15,000 psi H_2O only above about 800°C, with a new compound designated $C_2SH(Y)$ stable below this temperature. The *p-t* relations between γ, α' and β Ca_2SiO_4 have been studied under N_2 pressure and in "directed pressure" apparatus both by static methods and DTA. The results are not conclusive enough to establish the enhanced stability of larnite under pressure.

NEW DATA BEARING ON THE CRYSTAL CHEMISTRY OF THE SILICA POLYMORPHS

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The arguments against the validity of the generally accepted relationships among the silica polymorphs are discussed. New hydrothermal and "dry" data suggest the following: Pure tridymite has probably never been prepared "dry" from quartz or cristobalite. Tridymite (as defined by its powder *x*-ray pattern) can be grown easily from "amorphous" silica, and with considerable difficulty from cristobalite under hydrothermal conditions. All starting materials are made from organic silica compounds in the absence of alkali and run in sealed *Pt* tubes. Quartz invariably transformed to cristobalite first. The use of water as a mineralizer is open to objection although infra-red studies do not reveal any water in the solid phases. The data appear to confirm 867°C. as the temperature of maximum stability for the quartz structure at atmospheric pressure. The *p-t* dependence of the high-low cristobalite transition has been determined (45°C. increase/1000 atmospheres).

Large discrepancies in the α-β quartz, α-β cristobalite, and quartz-tridymite cases between the thermochemical heats of transition and those calculated from *p-t* slopes are pointed out and ascribed to difficulties in thermochemical measurements and calculations. The unique thermal expansions of high quartz and tridymite make possible a very large change of $\Delta H_{trans.}$ with pressure (calculated as 100% for 2000 atmospheres), and this may account for part of the discrepancy in the quartz-tridymite cases.

SUBAERIAL LANDSCAPE EVOLUTION AND SOIL DEVELOPMENT IN A HUMID REGION*

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In drainage basins in the humid pre-Wisconsin drift region in Iowa, subaerial erosion surfaces occur in stepped sequence along the interfluves from the modern flood plains to the divides. The juxtaposed surfaces are separated areally and in elevation by topographic, pedologic, and mineralogic unconformities.

A high-level Yarmouth-Sangamon surface occurs on the divides and is characterized by thick and intensely weathered paleo-Planosolic and Humic Gley soils (gumbotil). An intermediate-level Late Sangamon erosion surface occurs along the interfluves below the Yarmouth-Sangamon surface and is separated from it by distinct breaks in slopes. The Late Sangamon surface is characterized by moderately thick, less intensely weathered paleo-Gray Brown Podzolic soils. A low-level Early Wisconsin erosion surface occurs along the interfluves below the Late Sangamon surface and is separated

* Contribution of Soil Survey Investigations, Soil Conservation Service, U. S. Department of Agriculture

from it by distinct breaks in slopes. The Early Wisconsin surface is characterized by thin modern relatively unweathered Brunizemic soils.

The erosion-surface characteristics and relationships preclude an evolution of the surfaces by a "downwearing" of the landscape. The "normal" process of evolution is a "backwearing" of an erosion surface into and below a pre-existing landscape. The older upland is stable and little modified by erosion, but subject to intensive weathering. During development of the younger, lower erosion surface, fresh parent material is exposed to a new cycle of pedogenesis. Thus, two surfaces that are juxtaposed areally and in elevation may be separated by topographic, pedologic, and mineralogic unconformities.

INTERMEDIATE STRUCTURES AS A PROBABLE FACTOR IN HALLOYSITE GENESIS

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Hydrated halloysite, $Al_4Si_4O_{10}(OH)_8 \cdot 4H_2O$, has not been synthesized, and consequently specific conditions required for its formation preferential to kaolinite have been unknown. Halloysite results from acid attack on alkali and alkaline earth-bearing rocks such as limestones, granites, and acid volcanic rocks associated with limestones. Portions of the nonequilibrium system involved (alkali-alkaline earth-alumina-silica-acid-water) were studied in an attempt to find why halloysite formed rather than kaolinite in such an environment.

Two compounds, closely approximating the hydrated halloysite structure, were synthesized in restricted portions of the systems $CaO \cdot Al_2O_3 \cdot SiO_2 \cdot Cl \cdot H_2O$ and $Li_2O \cdot Al_2O_3 \cdot SiO_2 \cdot SO_3 \cdot H_2O$ during runs of 3 days to 3 weeks at 80°C. Like hydrated halloysite these compounds have a basal spacing of 10.1A and collapse at room temperature upon loss of the interlayer water. The lithium compound forms organic complexes in the same manner as hydrated halloysite. Possible formulas are $Ca_4Al_8H_{16}O_{10}(OH)_8 \cdot nH_2O$ and $LiAl_5Al_4O_{10}(OH)_8 \cdot nH_2O$ although their exact structures and formulas remain to be determined. The crystallization of these aluminates, with a hydrated halloysite structure, in an acid, siliceous system containing alkalis and alkaline earths indicates they probably form the initial lattice into which the silica subsequently enters. The sequence in an excess water system can be expressed as follows:

Alkaline earth + alkali + acid + alumina and silica gels → intermediate aluminate with hydrated halloysite structure + silica gel + acid → hydrated halloysite + (alkaline earth, alkali and acid) ↑ or an associated mineral such as alunite.

ENGINEERING GEOLOGY OF TACONITE HARBOR, MINNESOTA

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The Erie Mining Company's taconite project includes construction of a 75-mile railroad from Aurora, Minnesota, to Lake Superior, and port facilities at Taconite Harbor, about 80 miles northeast of Duluth.

The company selected a good site for a small harbor off the mouth of Two Island River, where Bear and Gull islands, supplemented by breakwaters, will provide shelter.

The rocky coast here consists mainly of Keweenawan amygdaloidal basalt flows. These were excavated back from the lake to widen the harbor and develop a vertical rock face for a bulkhead-type ore dock. This permits ships to lie close alongside the pellet bins and under the shuttle-conveyor loading belts. Ship-loading time will be as little as 1 hour.

In view of the normally fractured condition of the otherwise competent basalts, the lakeward dip of the flow contacts, and the requirement of a vertical rock face about 60 feet high, a 2-foot 6-inch reinforced concrete facing wall was placed as a dock face. This was strongly doweled to the rock to

form a "monolithic" mass under the pellet bins and ore-loading machinery. In addition the rock was grouted before and after excavation of the face. The rock face was line drilled on 1-foot centers, and harbor excavation and construction of the dock face was carried out in the dry behind a cellular cofferdam.

Breakwater core material was derived from harbor excavation, excellent armor stone from a large anorthosite mass at Carlton Peak, 6 miles away.

TITANIFEROUS SEDIMENTARY ROCKS IN THE CUYUNA DISTRICT, MINNESOTA*

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The ore-yielding main iron formation of the Cuyuna district, Minnesota, is stratigraphically overlain by 300 feet of titaniferous sedimentary rocks, and a field test for titania has been effective as a supplement to customary stratigraphic studies. The titanium is in leucoxene.

The sedimentary rocks of the district are highly folded, and the main iron formation serves as the reference for relative stratigraphic position. The strata older than the main iron formation are light-gray argillites and siltstones with local lenses of quartzite near the upper contact; the sequence contains about 0.5 per cent titania. The main iron formation is a persistent layer of ferruginous, chemically precipitated sediments containing about 0.2 per cent titania. The strata younger than the main iron formation are gray or black argillites, partly carbonaceous, partly ferruginous, and are transitional into lenses of lean iron formation. At the base of this younger sequence, tuffs without flows are predominant, but altered basalt flows are locally interlayered; these tuffaceous units contain 1.5 to 3.4 per cent titania. Most of the titaniferous zone, however, is argillitic and is similar to argillites higher in the younger sequence, which contain less than 1.5 per cent titania. The high titania content in argillites of the 300-foot zone above the iron formation suggests a geologic history in some way similar to the volcanic rocks at the base; probably the titaniferous argillite is reworked decomposed tuff. A few other titaniferous rocks, mostly intrusives, have been found in rocks below, within, and above the iron formation.

ALTERATION RELATED TO COLORADO PLATEAU ORE DEPOSITS

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Two types of diagenetic changes have taken place in sedimentary rocks of the Colorado Plateau. One type, characterized by reddish colors, involved oxidation of original magnetite, ilmenite, and other heavy detrital minerals, and local movement of iron from these minerals to form hematite coatings on detrital grains in the sediments. A second type, characterized by gray to greenish-gray, occurred only in the vicinity of carbonaceous material deposited with the sediments, where reducing conditions prevailed. In these locales iron, removed from original detrital grains, moved locally and was redeposited as pyrite.

Another type of alteration, obscure because of its similarity to one type of diagenetic change, took place after the others. It is manifested by gray to greenish-gray colors and is found both where there is no carbonaceous material and in carbon-bearing light-gray sediments close to ore deposits. Loss of iron-bearing minerals, formation of anatase, and recrystallization of barite characterize this alteration.

It is concluded that carbonaceous material, deposited locally in the sedimentary rocks of the Colorado Plateau, developed a diagenetic change under reducing conditions while oxidation prevailed elsewhere. Later, ore-forming solutions with strong solvent powers moved laterally through the sedi-

* Publication authorized by the Director, U. S. Geological Survey

mentary rocks, leaching and recrystallizing rock constituents untouched by the earlier changes. Where these solutions traversed carbon-bearing strata, uranium-vanadium ore deposits formed in the strongly reducing environment.

SEDIMENT RELATIONS TO PERIMETER OF MISSISSIPPI DELTA*

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Extensive analyses of the 900 samples, collected largely by P. C. Scruton from the margins of the Mississippi birdfoot delta, have indicated a pattern believed to characterize the sedimentation of many large marine deltas. The sediment units to the east appear to fit into the classical concept of topset, foreset, and bottomset beds. The topset include subaerial delta deposits and delta-front platform deposits. The foreset beds, differing radically from the topset, are being built forward on a very gentle slope, mostly 1 per cent or less, so that the overlapping topset beds have little discordance. The bottomset beds, forming on the flat shelf beyond the pro-delta slope, are distinctive. The bottomset beds have encroached eastward on old shelf deposits, but the mineral composition shows that from time to time the latter are carried westward, mingling with the delta-derived bottomset beds.

The different units can be identified by ratios of such constituents of the coarse fraction as wood fibers, aggregates, and mica which abound near the delta and are scarce outside; whereas Foraminifera, echinoids, mollusks, and glauconite are scarce or absent near the delta and reach a maximum on the flat shelf near the base of the pro-delta slope. In addition the laminations which are commonly present in the topset beds (other than marsh deposits) help distinguish them from the foreset and bottomset beds.

GRAVITY OBSERVATIONS AT SEA IN USS TORO

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Gravity anomalies for 125 observations made in USS TORO (SS 422) between the eastern coast of the United States and Bermuda are presented with previous gravity data in the area. The largest gravitational feature in this area is the belt of anomalies associated with the continental margin, due largely to edge effects.

Two new structure sections deduced from gravity anomalies across the continental margin are shown. Previous conclusions of Worzel and Shurbet (1955, p. 468) based on similar studies are confirmed—that the transition from continental to oceanic crustal structure occurs within 200 km, centered near the 1000-fm curve, that the maximum sedimentary thickness occurs at the base of the continental slope, that the greatest volume of sediments occurs beneath the continental rise, and that the Gulf of Maine is underlain by a crustal block of continental thickness.

SUBAERIAL AND SUBMARINE EROSIONAL ENVIRONMENTS

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The formation of submarine canyons has been attributed to two conflicting origins—subaerial or submarine processes. Certain submarine-canyon systems have been designated as products of turbidity currents; others found on the wide Atlantic shelf are more suggestive of subaerial erosion.

A new method for measuring the internal and external geometric constructions of subaerial basins

* This investigation was supported by a grant from the American Petroleum Institute, Project 51

or submarine-canyon systems allows basins and canyons of statistically similar constructions, regardless of areal dimension, to be compared directly.

Based on Strahler's modification of Horton's ordering system, orientation and length measurements of the ordered segments within a basin are used in two sequential tests. These tests are designed to test randomness within the geometry of the canyon or stream patterns. The orientation measurements are taken from a fixed base line within the basins, such that the frequency distribution can be compared directly for geomorphic and hydrologic form. The variance and form of the frequency distributions are highly significant as indicators of the dynamics and control factors of the past and present erosional environments.

Preliminary results indicate that the canyon environment off the Atlantic coast, especially in the region near the Hudson Submarine Canyon, is related to typical badland-type erosional processes. Canyon systems found in the California area are similar to younger types of subaerial basins and show the effects of marked structural control.

AGE OF THE ORDOVICIAN ENGLISH HEAD FORMATION

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The English Head formation of Anticosti Island, Quebec, has been considered to be of Richmond age since early in this century. It rests on beds of Holland Patent age, and the nature of the contact is unknown. It underlies beds of Richmond age. Its own fauna is largely endemic but contains elements which elsewhere are found in beds ranging from Trenton to Richmond. Those similar to Richmond forms are few, considering that ecotypically the English Head resembles the Ohio-Indiana Richmond. For these reasons, the English Head is interpreted as a carbonate facies of some part of the Covington of Ohio and the Lorraine of New York and Southern Quebec. The theoretical bases of correlation by paleontology are examined, and necessary limitations on the doctrine of "first appearances" are suggested.

INTERPRETATION OF STRATIGRAPHY OF A PORTION OF THE GRENVILLE SUBPROVINCE IN SOUTHEASTERN ONTARIO

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In the northern part of Frontenac County, in an area about equidistant from Madoc, Ottawa, and Kingston, it is possible to interpret with confidence the age relationships in a considerable vertical section. The oldest rocks are metamorphosed pillowed lavas and pyroclastics. These are followed by paragneiss and white to cream-colored metalimestones, in that order but partly intercalated. The next younger assemblage includes metaconglomerate, closely similar to that which has been referred to the Hastings series in other areas, together with metaquartzite and varved schists. These are followed by mafic schists for which there is some evidence of volcanic origin.

All this sequence occurs in a wedge-shaped area between two major fault zones, on either side of which correlations cannot be made positively, but there is good evidence that certain bluish metalimestones, characterized partly by interbedded quartzite, are still younger. It seems likely that most of the metalimestone of the belt which extends from the well-documented Claire River syncline near Madoc to Arnprior northwest of Ottawa is of this youngest age.

CRYSTAL STRUCTURE OF URANOPHANE

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Zero-level Weissenberg photographs about the b axis and [0kl] precession photographs have yielded a compatible crystal structure for uranophane. The space group is C_s^2–$P2_1$, and the cell con-

stants are $a = 15.97$A, $b = 7.07$A, $c = 6.68$A, and $\beta = 97.3°$. There are two molecules with the formula $[Ca(H_3O)_2]$ $(UO_2)_2(SiO_4)_2 \cdot 3H_2O$ in the unit cell.

The structure consists of sheets with the formula $[(UO_2)_2(SiO_4)_2]^{-4}$, which are parallel to the perfect (100) cleavage. The fiber direction is parallel to the b axis and lies in the plane of the sheets. The axis of the linear uranyl ion is normal to the sheet with the U–O distance 1.91A, and five other oxygens all from independent SiO_4 tetrahedra form a planar ring around this ion giving the uranium a total co-ordination of seven. The fibrous habit is a result of this co-ordination which produces a double chainlike structure within the sheet.

The sheets, which are $\frac{a}{2}$ apart, are stacked on each other with a regular shift of 1.01A parallel to the c axis and an alternating shift of 0.52A parallel to the b axis. Calcium atoms and hydronium ions lie between the sheets holding them together. The calcium atom has a co-ordination of 8 including 3 oxygens in the sheets, 2 hydronium ions, and 3 water molecules.

GIANT COMPOSITE BARCHANS OF THE NORTHERN PERUVIAN DESERTS*

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Composite barchans of unique characteristics occur in the Sechura Desert (Lat. 5°30′ to 6°10′S.) and in the Viru area (Lat. 8°24′S.), of the northern Peruvian coastal region. Ground plan is similar to that of barchans in general, ranging from crescentic to rudely triangular, with numerous variations in detail, and in degree of bilateral symmetry. Linear dimensions range from 5 to 18 times those of associated simple barchans, heights from 60 to 225 feet, widths from about 1000 to 6000 feet, and lengths (measured parallel to wind direction) from about 800 to 3000 feet. The windward slope is characterized by minor barchans and transverse dunes superimposed on the major form. The lee slope ranges from a nearly continuous slip face to an irregularly terraced descent. At many places, ordinary barchans occur on both windward and leeward sides, and long trains of barchans commonly are aligned downwind from the horns of the major forms.

Composite barchans seem best explained as the result of a long process of overriding of initially slower-moving sand accumulations by faster-moving barchans from the windward direction, with ensuing fusion of the latter with the mass of the former.

BERYLLIUM IN THE ASH OF AMERICAN COALS

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Spectrochemical determinations of beryllium (sensitivity 1×10^{-4} to 5×10^{-5} per cent) in the ash of columnar coal samples collected from most of the productive fields of the United States show that: (1) beryllium is present in about 95 per cent of all samples examined, (2) the average content in the ash of 1123 samples is about 4.5×10^{-3} per cent. This value is more than 20 clarkes higher than the value of 0.0002 per cent or less given by Sandell for the average abundance in the upper lithosphere. (3) Concentrations of beryllium, like those of certain other elements such as germanium and molybdenum, are not uniform. Most coals containing beryllium are found in the Interior province; they account for 99.2 per cent of all the samples analyzed. The average concentration in these fields is more than 26 clarkes, but individual samples may contain 100–200 clarkes. (4) Beryllium is least concentrated in the Rocky Mountain province and was found in only 77 per cent of the samples examined. The average concentration of beryllium in the coal ash from this province is low (about 4 clarkes).

The maximum concentration of beryllium (more than 850 clarkes) is found in two consecutive blocks of low-ash coal from the eastern Kentucky field. It represents 140 grams of beryllium oxide in a ton of coal.

* Based on research carried out under the auspices of the Office of Naval Research, Contract Nonr-583 (06)

ANCIENT LAKE PAYETTE IN IDAHO

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Kirkham's classification of the Payette formation as "intermontane beds" and the Idaho formation as "basin beds" clarified the earlier confused conceptions of these beds. The stratigraphy is more complex, however, and our knowledge of the geology of southern Idaho has been greatly increased recently. Field work since 1946 and examination of 10 miles of drill cores have indicated that not one lake but many existed. Lake Payette, by definition, was a lake in which diverse sediments, chiefly light-colored shales and sparse lignite beds, accumulated during a quiescent period.

Flood-plain, tuff, and lake deposits lie between many lava flows in the Columbia River basalts in southwestern Idaho and southeastern Oregon indicating several quiescent periods. The Latah formation, the diatomaceous sediments in Richland Valley, Oregon, and the fossil fish beds at Brownlee Dam accumulated in different lakes in different periods. Thus the Payette is a group of local deposits ranging in age from the earliest to the latest of the Columbia River basalts (Miocene). They include silicic ejecta, indicating that eruptions of rhyolite, latite, and andesite had begun to the east. The Payette group can be distinguished in most places by conformable relations with the folded and faulted Columbia River basalts. They definitely pre-date the great Snake River downwarp and the epoch of north-south block faulting associated with it. A great many sedimentary beds associated with weathered brown lavas have been classed as Payette, but not all brown lavas in the area are Columbia River basalts.

LAKE IDAHO PROBLEM

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The "Lake Idaho" formation comprises a group of deposits separated from the Columbia River basalts and associated sediments by angular and erosional unconformities. (1) The earliest are firmly cemented sandstone, conglomerates, and light-colored shales. Remnants of the formation are now buttes and carry cinnabar at Nutmeg Mountain. (2) After uplift and erosion of the earliest deposits thick shale beds, thin silt beds, and scarce tuff beds were deposited. (3) Several hundred feet of grits, and a little gravel lie unconformably on shales in the Boise-Weiser area. All three formations are warped sufficiently to form the Weiser-Midvale anticline and the folds extending toward Owyhee Reservoir. Locally all three contain basaltic lava.

In the Grandview-Twin Falls area the Banbury basalts and their interbedded sediments lie on the silicic eruptives and were considerably downwarped, eroded, and weathered before deposition of the Hagerman fine-grained silty fluviatile deposits. Scattered basaltic and rare silicic eruptions occurred throughout the area as tuffs, and flows are interbedded with all the sediments, but the brown color of the basalts distinguishes them from the later blue-black Quaternary "Snake River" basalts. Locally other sedimentary flood-plain deposits lie unconformably on the Hagerman and Banbury formations.

An extensive erosion cycle terminated the "Basin Bed" epoch, probably at the close of the Pliocene, and cut extensive pediments in the margins of the "lake beds" and adjacent mountain fronts. Gravels covered the lower parts of the plain and remain today as caps on the mesas.

PRELIMINARY AGE DETERMINATIONS OF SOME URANIUM ORES FROM THE BLIND RIVER AREA, ALGOMA DISTRICT, ONTARIO, CANADA

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Ages were calculated on four samples of uranium ore, and isotopic analyses were made of lead extracted from one galena and two pyrite concentrates, from the Pronto and Quirke Lake mines. The

uranium ores analyzed were high grade, free from secondary uranium minerals, and contained abundant pyrite. The Quirke Lake sample also contained abundant microscopic galena. Uraninite was the major uranium mineral in the four ore samples.

These mines are in conglomerate of the Mississagi quartzite (lower Huronian). The conglomerate has not yet been dated, but a pre-Huronian igneous rock from northern Michigan has a lead-alpha zircon age of approximately 1300 million years. Isotopic analyses of lead in the pyrite and galena concentrates indicate the presence of radiogenic lead with a Pb^{207}/Pb^{206} ratio of at least 0.14—equivalent to a maximum age of 2250 million years—appreciably older than the inferred age of the enclosing Mississagi. This old radiogenic lead may be from detrital minerals or pre-existing ore deposits in the basement complex. The calculated ages of the Blind River ores in millions of years are:

Mine	Sample	Pb^{206}/U^{238}	Pb^{207}/U^{235}	Pb^{207}/Pb^{206}	Pb^{208}/Th^{232}
Pronto	461D	340	520	1400	345
Pronto	461E	440	600	1250	380
Pronto	464	400	570	1350	410
Quirke Lake	463A	1850	2060	2250	3100

Presence of an old radiogenic lead similar to that in the pyrite and galena can explain the $Pb^{206}/U^{238} \ll Pb^{207}/Pb^{206}$ age sequence observed. If this explanation is correct, the Blind River ores are probably not older than Paleozoic.

DIMENSION SPACE APPLIED TO GEOMORPHOLOGY

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Dimension space, a geometrical concept of dimensional analysis introduced by Stanley Corrsin in 1951, is readily adapted to quantitative geomorphology, both in description of landform geometry and in study of dynamics of erosion, transportation, and sedimentation. The three primary, basic properties of mass, length, and time are represented by orthogonal co-ordinates scaled in integer powers to form a cubical dimension-space lattice in which physical geomorphic properties are represented by unique vectors extended from the origin to an appropriate lattice point.

In drainage-basin geometry, such properties as stream and slope-length, constant of channel maintenance, basin area, and landmass volume lie at positive integer points on the length axis, drainage density and stream frequency at negative integer points. The origin of the co-ordinate system represents dimensionless quantities such as stream order, bifurcation and length ratio, ground and channel slope, hypsometric integral, ruggedness number, and all strike or azimuthal measurements. Dimensionless products involving three or more physical properties, such as the Horton, Reynolds, and Froude numbers, are represented by vector polygons attached to the dimensionless origin.

Dimension space is easily grasped by geologists skilled in structural visualization and requires only modest mathematical knowledge. Thus there is opportunity to place the study of geomorphic processes and forms on a sound mechanical basis through dimensional analysis. When this is done, quantitative information collected and analyzed by the geomorphologist becomes directly useful to engineers in fields of hydrology, soil erosion, sedimentation, and soil mechanics and can be readily introduced into dimensionally homogeneous equations.

GEOMORPHIC RELATIONS OF SILT DEPOSITS IN THE MATANUSKA VALLEY, ALASKA

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During the last glacial maximum, the areas of significant silt deposits were occupied by Knik ice. The sinuous gravel ridges southwest of Palmer and the Palmer fan were successively developed by

the Matanuska River in areas occupied by Knik ice which became progressively less active. The alluvial features extended southward to the margin of the active ice in the main Knik valley south of Bodenberg Butte.

When the Knik ice retreated from the main valley south of Bodenberg Butte, the Matanuska River incised its channels below the level of the alluvial surfaces. Extensive alluvial fans were deposited in the main Knik valley causing alluvial drowning of the valley above Jim Creek and producing the present Knik River flood plain in that area. This makes the Knik flood plain one of the most recent features of the area.

The principal silt deposits are younger than the alluvial surfaces north of Bodenberg Butte and older than the incision of the Matanuska River channels. Relations of the silts to the alluvial surfaces and to kettle holes in these surfaces indicate a short period of silt deposition.

The silt deposits are older than the formation of the Knik flood plain which is commonly assumed to be an important source area. This and additional evidence from thickness and textural analyses requires modification of the prevailing eolian theory for the origin of the silts.

OSTRACODE ZONES OF LOWER MIDDLE ORDOVICIAN IN THE EASTERN UNITED STATES

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Two zones, based on Ostracoda, are recognized in lower Middle Ordovician strata of Virginia, Pennsylvania, New York, and Vermont. The lower zone, based on a new species of *Aparchites*, is represented in Day Point and lower Crown Point formations of Lake Champlain area, Loysburg and lower Hatter formations of central Pennsylvania, and upper Row Park and lower and middle New Market formations of southern Pennsylvania. The upper zone, based on *Monoceratella* cf. *teres* Teichert, is represented in Crown Point of Lake Champlain, upper Hatter and lower Benner of central Pennsylvania, uppermost New Market of southern Pennsylvania, and Lincolnshire and lower Edinburg formations of Shenandoah Valley, Virginia.

Furthermore, the lower Middle Ordovician ostracodes of central Appalachians apparently represent a biofacies separate from that in Lake Champlain area. Species restricted to lower zone in Vermont-New York include those of *Aparchites*, *Euprimitia*, and *Monoceratina*; in the central Appalachians restricted species include those of *Leperditia*, *Leperditella*, *Briartina*?, *Opikella*, and a primitive kirkbyid. The upper zone has, in both biofacies, new species of *Eurychilina*, *Budnianella*, *Ctenobolbina*, and *Laccochilina*? as well as *Isochilina limatula* (Raymond); in northern biofacies upper zone has new species of *Aparchites*, *Primitiella*, *Tallinella*, *Thomasatia*, *Maratia*, *Budnianella*, *Alanella*, *Monoceratina*, a primitive *Sclerocypris*-like ostracode, and a new genus; corresponding assemblage in central Appalachians has new species of *Ectoprimitia*, *Bassleratia*, *Ctenobolbina*, and *Winchellatia*. Northern biofacies bears relationship to that in Scandinavia and Esthonia, whereas the southern resembles that in Midcontinent United States.

APPLICATIONS OF THE DIFFERENTIATION INDEX TO PETROLOGIC PROBLEMS

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Bowen demonstrated that fractional crystallization in magmas will enrich the residual liquid in alkali-alumina silicates, resulting in a tendency for all magmas to change in composition toward the system quartz-nepheline-kallophylite, "petrogeny's residua system". This experimentally proven tendency which has been confirmed by chemical studies of the rocks themselves can be used to express numerically the extent to which a given rock approaches petrogeny's residua system by adding together the normative amounts of quartz, albite, orthoclase, nepheline, leucite, and kaliophilite in

the rock. This value, the differentiation index, can be used to construct variation diagrams of igneous rock series.

Variation diagrams of D.I. vs. silica from individual volcanic areas converge at low D.I. values, but they do not cross one another—suggesting that once an alkaline rock, always an alkaline rock. At present we do not have a single example where the variation curve of the rocks from an alkaline area intersects a curve of the variations in an area of silicic rocks.

The D.I. has proved useful as a simple means of classifying igneous rocks. For example, the average alkali granite has a D.I. of 92, calc-alkali granite 88, granodiorite 73, tonalite 65, monzonite 57, diorite 36, alkali gabbro 22, olivine gabbro 19, and peridodite 6.

Diagrams prepared by plotting the D.I. against the per cent of oxides for 5000 analyzed rocks in Washington's tables will be presented.

VARIATIONS IN THE ABUNDANCE OF TRACE ELEMENTS IN A EUPELAGIC ATLANTIC CORE

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A eupelagic Atlantic core, A180-76, 420 cm long was sampled at 5-cm intervals and analyzed chemically and spectrographically for total calcium carbonate, magnesium, strontium, copper, nickel, chromium, and lead. Generally the abundances of Mg, Cu, Ni, and Cr are direct functions of the per cent of lutite fraction in the core. Lead and strontium, though showing some variation, do not fluctuate with the lutite fraction. Since the core is composed of 78.3% $CaCO_3$ on the average, this is interpreted to mean the Pb and Sr are associated with the carbonate fraction.

A significant feature in the core is that there are high values of Cu, Ni, and Mg concentration in certain sections which occur where either a greenish hue was observed in the fresh cores or the abundance of diatoms is known to be high. The high concentration of these elements at these points may be related to their presence in porphyrin-type compounds associated with organic remains. However, it is not to be inferred that this is a major feature accounting for the removal of trace elements from the sea. The average concentrations of the elements in the deep-sea core are: 31.3% Ca, 3800 ppm Mg, 1600 ppm Sr, 18 ppm Cu, 15 ppm Ni, 11 ppm Cr, and 4 ppm Pb. Though deep-sea plankton concentrate the minor elements in their tissues it is evident that in most cases they are not incorporated in the deep-sea sediments.

SYNTHESIS OF SPURRITE AND THE REACTION: WOLLASTONITE + CALCITE $\rightleftharpoons$ SPURRITE + CARBON DIOXIDE

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The P_{CO_2}-T curve for the reaction: $3CaCO_3 + 2CaSiO_3 \rightleftharpoons 2Ca_2SiO_4 \cdot CaCO_3 + CO_2$ has been determined experimentally between 700° and 1000°C. At 1000, 3000, and 5000 lbs./in.^{2} of CO_2 the curve passes through 800°, 930°, and 1000°C. respectively.

The reaction has been made to go both ways, and tilleyite, $Ca_5Si_2O_7 \cdot 2CaCO_3$, does not occur as a stable phase between the low- and the high-temperature assemblages. It appears that tilleyite has no place as a normal decarbonation index mineral in the system CaO-SiO_2-CO_2 (equivalent to siliceous limestones) at least between 1000 and 5000 lbs./in.^{2} of CO_2.

Between 500 and 5000 lbs./in.^{2} of CO_2 the formation of wollastonite from calcite and quartz, the first stage in the decarbonation of siliceous limestone, occurs approximately 400°C. lower than the second stage—the formation of spurrite as described above.

The absence of spurrite at granite-limestone contacts, where the temperature is probably of the order of 700°–750°C., suggests that the CO_2 pressure at such contacts is high enough to prevent this second stage from taking place.

REINTERPRETATION OF THE IOWAN DRIFT BORDER IN EASTERN IOWA

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Uncertainty about the limits of Iowan glaciation in eastern Iowa has existed for a long time. Published maps showing the Iowan drift border have been compiled from more than 20 county reports written early in the century. The boundary lines on the county maps were apparently drawn on the basis of some of the following criteria: the outermost extent of Iowan till, the inner edge of "marginal" ridges of loess and sand, and a change from youthful to mature topography. As compiled, the border was irregular with extreme digitations. The map pattern suggested that thin tongues of ice flowed down interfluves, leaving intervening valleys unglaciated.

Re-examination of the border zone suggests that some areas of youthful topography formerly thought to have been covered by Iowan ice are youthful in appearance only because they lie relatively distant from major streams. Other areas of mature topography were found to be mantled with Iowan drift. Many of the marginal ridges of loess and sand lie east and northeast of streams that were glacial drainageways. These ridges are thought to be in part built of aeolian deposits derived from outwash rather than from material blown off the Iowan ice. A few patches of Iowan drift have been found on the floors of the valleys between glaciated uplands and below the Niagaran escarpment. Present indications are that Iowan glaciers occupied valleys beyond the present boundary of the drift, while post-Iowan erosion and deposition have removed or buried most of the drift in these valleys.

CAROTENOIDS AND CHLOROPHYLL-LIKE PIGMENTS IN A 20,000 YEAR OLD SEDIMENT FROM SEARLES LAKE, CALIFORNIA

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Carotenes and xanthophylls were present in equal amounts. The following carotenes were identified on the basis of cochromatography and superposability of absorption spectra with the authentic compounds: α-carotene, β-carotene, neo-β-carotene B, and neo-β-carotene U. Six other carotenes were present but not identified. The absence of cis-isomers of carotenoids in recent sediments indicates that their presence here is due to diagenetic change. The chlorophyll-like pigments were soluble in methanol, but not in petroleum ether or acetone.

SYNTHESIS OF CUSPIDINE, $3CaO \cdot 2SiO_2 \cdot CaF_2$

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Cuspidine was synthesized by solid-state reactions, hydrothermally, and by crystallization from melts. Efforts to synthesize custerite, $3CaO \cdot 2SiO_2 \cdot Ca(F, OH)_2$, by substituting hydroxyl for fluorine in the cuspidine structure, were not successful. Synthetic cuspidine is biaxially positive with $\alpha = 1.591$, $\beta = 1.595$, and $\gamma = 1.602$, 2V calculated $= 52°$. The extinction angle measured // to c $= 7°$. Synthetic cuspidine melted congruently at 1410°C. $\pm$ 10° at approximately 1 atmosphere of fluorine using a modified quench technique. A differential thermal-analysis curve gave only one reaction

peak (exothermic) at 1410°C. On prolonged heating at elevated temperatures cuspidine alters to larnite, $2CaO \cdot SiO_2$, with the escape of fluorides.

ORIGIN AND OCCURRENCE OF URANIUM IN NORTHERN MICHIGAN

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Pitchblende and the secondary uranium minerals metatyuyamunite, meta-autunite, metatorbernite, and bassetite are associated in Northern Michigan with pyrite, chalcopyrite, sphalerite, galena, bornite, and greenockite in middle Precambrian (upper Huronian) rocks. A study of the deposits suggests that the uranium and associated metals were leached from carbonaceous slates during weathering and deposited adjacent to oxidized rock under reducing conditions. Three of the four pitchblende deposits are associated with soft-iron ores, which some consider to have also formed by weathering processes. Evidence to support the theory of origin is: (1) uranium deposits, although widely distributed, are in or adjacent to carbonaceous slates that commonly contain 0.004 per cent uranium as well as appreciable amounts of other metals; (2) deposits are localized at or near the contact between weathered or oxidized rock and unaltered rock; (3) leaching experiments made with the carbonaceous slates showed that all the elements deposited with the uranium were concentrated in the leachate; (4) pyrite-bearing carbonaceous slates not only have provided an acid sulfate water that would dissolve uranium under oxidizing conditions but also have provided an environment sufficiently reducing the precipitation of pitchblende and sulfides below the zone of weathering; (5) no uranium has been found in the many base-metal sulfide deposits not associated with carbonaceous slates and oxidized iron formation in northern Michigan; and (6) the chemistry of uranium deposition and the Eh and pH stability fields of the introduced minerals are consistent with the proposed theory.

INVESTIGATIONS ON THE GEOCHEMICAL DISTRIBUTION OF LEAD

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A quantitative spectrochemical double-arc method with Bi-standard is applied to new lead determinations in rocks and rock-forming minerals (sensitivity $\sim$ 0.0001%Pb).

More than 500 analyses of representative rocks, including literature references, are discussed.

The average Pb content of potassium feldspars and micas ($\sim$0.0025%) exceeds that of the lithospere (0.0015%); amounts up to 0.010% occur in pegmatitic feldspars. Olivine and quartz contain much lower concentrations, which is to be expected from their structural properties. Pb'' replaces potassium in its structural positions owing to similar ionic dimensions. Adularia, some feldspathoids, and zeolites are favored in the lead replacement of K, Na, or Ca.

Average lead abundances are: granites 0.0019%; granodiorites, 0.0015%; diorites 0.0010%; basalts 0.0006%; ultrabasic rocks 0.0003%.

The behavior of lead during rock weathering and its mobilization are investigated. Low solubility of some compounds, adsorption, and action of certain organisms cause local concentrations in some sediments. The following are averages: nonpelagic argillaceous rocks 0.0020%; sandstones 0.0007%; limestones and dolomites 0.0009%. Influence of volcanic exhalations on high lead concentrations (up to 0.014%) in pelagic clays is considered.

Lead occurrence in metamorphic rocks and minerals is compared with that of sedimentary and magmatic origin. During the last $3.3 \cdot 10^9$ years total amount of lead in the earth's crust is asssumed to be increasing by only 20% from radiogenic sources.

Most of geochemical characteristics of this element are to be explained by the ionic dimensions and $-$ charge of Pb''.

ROLE OF MARINE-NONMARINE TIME-SCALE DISPARITIES IN THE INTERPRETATION OF CORDILLERAN TERTIARY HISTORY*

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The middle and late Tertiary history of western United States is generally characterized by two major regional pre-Cascadian episodes of subsidence and accumulation, each followed by widespread deformation-erosion.

Although the two depositional sequences have been properly separated locally by many investigators throughout the West, their regional distinction and original continuity has been generally unappreciated because of frequent failure to observe that: (1) their relationship is regionally unconformable; (2) each overlies rocks of any earlier age; (3) in many areas each is preceded and followed by a demonstrable faunal hiatus; (4) in most areas they are differentially deformed, intruded, and mineralized; (5) each contains widely distributed, unique, specific sedimentary and volcanic lithologies; (6) time-scale disparities tend to dissociate equivalent marine and nonmarine successions.

The earlier sequence is essentially "latest Eocene and Oligocene" in the western interior on the basis of vertebrates, but "latest Eocene to middle Miocene" (marine microfaunal) in the coastal region.

The following hiatal and orogenic episode occupies most of the vertebrate "Miocene," but only a short interval (commonly unrecognized) in the marine microfaunal "late-middle Miocene."

The later sequence contains abundant "late Miocene and early Pliocene" vertebrates but is largely confined to the marine "late Miocene."

The onset of the following Cascadian orogeny is interpreted as "middle Pliocene" on the vertebrate scale, but "earliest Pliocene" on the marine microfaunal scale.

Major Cordilleran middle to late Tertiary events, therefore, may be delineated only by appropriate adjustment of correlations for the incongruities of the marine microfaunal and vertebrate time-stratigraphic "standards."

GLACIAL GEOLOGY OF SOUTHWEST FLANKS OF VOLCANO IZTACCIHUATL, MEXICO

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Late Pleistocene glaciation on the southwest flanks of volcano Iztaccihuatl, Mexico, is exhibited by a series of moraines, faceted valley slopes, striated ledges, erratic boulders, small outwash terraces, and features of downslope movements. Interpretation of this evidence, based in part on position and erosion of moraines and on a stratigraphy of pyroclastic ejecta, suggests a sequence of three older glacial substages with large moraines at 3100 m to 3500 m in deep canyons, an insignificant intermediate substage with small moraines at 3710 m to 3773 m, and an important substage with prominent moraines at 4000 m to 4450 m.

Four small fresh rubbly moraines are built within larger valley heads. Many smaller valley heads contain only mudflow deposits, embanked gullies, talus, and protalus ramparts.

METABASALTIC DIKES IN THE BAKERSVILLE-ROAN MOUNTAIN AREA, MITCHELL COUNTY, NORTH CAROLINA

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Metabasaltic dikes up to 60 feet thick intrude the northwest limb of the southwest-plunging synclinorium underlying the Spruce Pine District. Dike contacts sharply crosscut plane-foliated and crenulated quartzofeldspathic gneiss and zones of brecciated gneiss.

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All dikes are metamorphosed and may be grouped into two principal rock types. Metadolerite has typical subophitic texture; clouded labradorite laths partly recrystallized to granules; clouded augite with rims of hornblende, almandine, diopside, and biotite; and crystal clusters of magnetite-ilmenite. Grain sizes range from 0.5 mm to 5 mm and generally decrease with more complete recrystallization. Amphibolite dikes have granoblastic texture and contain unclouded andesine, hornblende, almandine, biotite, and magnetite-ilmenite.

Orthoamphibolites formed from gabbroic rocks apparently related to the Bakersville-Roan Mountain dikes. These Toecane-type amphibolites contain hornblende and andesine with minor quartz, biotite, magnetite-ilmenite, sphene, and almandine.

K/A age determinations indicate a Late Precambrian age for the metamorphism of both dikes and country rocks.

Several amphibolite and metadolerite dikes are alternately found in a few hundred feet of outcrop, and dikes are emplaced within tens of feet of Toecane-type amphibolites. This rapid areal change in lithology may indicate that (1) basaltic magma intruded throughout the middle and late phases of a metamorphic cycle, and (2) variation in water content and stress field obtained between near-by dikes during a later metamorphic cycle.

K/A and U/Pb age determinations on pegmatites in the district indicate an Ordovician age for these intrusions.

EVOLUTION OF MOUNTAIN SYSTEMS

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Cover rocks of fossiliferous limestone-shale-sandstone a few thousand feet thick widely obscure the basement. Their accessibility, ease of study, and economic importance have given an unwarranted emphasis to them and to the last one sixth of recorded geological time. This distortion conceals the regular evolutionary sequence of mountain building which has followed these stages.

Traced seaward the cover rocks thicken to shelf deposits (*e.g.*, Eastern United States coast). Off them in due course volcanic arcs form of andesitic lavas and graywackes (East Asia). After an active life of a few hundred million years, widespread granitization of the arc rocks is coupled with uplift in a "revolution". The resulting primary mountains (New England) are added to the basement. Erosion pours back arkosic sediments onto the inner unaltered cover rocks which are also uplifted and disturbed as secondary mountains (Valley and Ridge province). Acid volcanic magma may again briefly break through the granitized arcs.

Age determinations have revealed many such paired systems in the later Precambrian. Thus the Grenville is the roots of a primary system of which the Keweenawan, Huronian, and Mistassini rocks are the secondary counterpart.

During the first third of recorded geological time (Keewatin and Timiskaming) conditions and mountain building were different from today.

To include Precambrian cover rocks without regard to age in a single Proterozoic group and all basement rocks in another Archean group is a confusing travesty which frustrates attempts to understand the evolution of mountains and the structure of continents.

PRECAMBRIAN CLASSIFICATION AND CORRELATION IN THE CANADIAN SHIELD

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This paper is a discussion of two problems: (1) how can the formations of the Canadian Shield be classified best according to age? and (2) over what extent of territory can Precambrian rock series be correlated with reasonable certainty? The outstanding accomplishment of geology has been the

world-wide correlation of rocks mainly by means of fossils. Although fossils are not abundant in the Canadian Shield, the first objective of Precambrian geology is correlation.

H. L. James, by the use of the names Lower, Middle, and Upper Precambrian, for the Precambrian rocks of northern Michigan, by implication at least, has proposed that this triple classification be extended to the whole Canadian Shield, an impossible undertaking. So far, only a dual classification of the rocks of the Shield, according to their relationship to the great unconformity beneath the (Huronian) Cobalt Series on Lake Timiskaming, has been attempted. Formations beneath this unconformity in the Timiskaming and Grenville subprovinces and less positively in the north or northwest subprovince are classed as Archean (Early Precambrian), those above as Proterozoic (Late Precambrian). Rocks in the northern part of the Shield are either assigned on lithological and structural evidence to the Archean or Proterozoic or are designated Archean or Proterozoic. In places the Archean classification has been confirmed by radioactive dating.

The Canadian Shield is divided geographically and geologically into subprovinces, which delimit the territory to which serial correlations can be extended. The elimination of subprovinces is therefore unwarranted.

EFFECT OF BLOOD ON CLAYS

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Various types of clays of known mineral composition were treated with beef blood, and the change of physical properties was observed. Mixtures of clay with blood generally increase the plasticity, the water resistance, and the dry compressive strength. Kaolinitic and illitic clays are more affected than an all-montmorillonitic Fuller's earth. The reworking of the treated dry clays decreased their liquid limit considerably.

The crystal lattices of the clays are not affected by the presence of blood. Tight monolayer coats of blood wrapped around the clay crystals may be responsible for the increase of the hardness and the water repellence. No explanation is possible yet for the lesser reaction of montmorillonite toward blood. The practical application of blood as a soil stabilizer is considered.

DISORDERING OF MINERALS BY THE ACTION OF FISSION SPECTRUM NEUTRONS

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Displacement theory indicates that between 10^3 and 10^4 atoms are displaced in solids by the knock-on mechanism per incident fast neutron collision. The energies of fission-spectrum neutrons and the collision cross sections with which we are concerned are such that with a time integral of fast flux equal to 10^{20} n/cm^2 an appreciable fraction of the atoms will be displaced by successive knock-on collisions. If all or a large part of these displacements are frozen in, the physical properties of the solid will be drastically altered.

A second mechanism, termed the thermal spike, may produce displacements in a different manner. As proposed by Seitz, there is a heated "wake" in the slowing-down process whereby the knocked-on particle heats up the material surrounding its track in the solid for times of the order of 10^{-12} sec. The temperatures which may be achieved in good insulators by this process may be several thousand degrees, with this extremely rapid quench. Hence, it is conceivable that this mechanism could result in phase transitions to metastable states in addition to just producing pure displacements.

On the submicroscopic scale the displacements are of two kinds, vacancies or Schottky defects, and interstitial-vacancy pairs or Frenkel defects. The defects produced in a large group of minerals exposed to fission-spectrum neutrons at approximately 100°C were observed by x-ray, thermal, and optical methods.

PLEATED FOLDING IN NORTHWESTERN MAINE

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Field mapping in seven quadrangles in northwestern Maine has revealed an interesting structural pattern. The middle Paleozoic metasedimentary rocks in all quadrangles except the Cupsuptic strike northeasterly and dip uniformly at 70° or more. Partially concordant and partially discordant plutons are interspersed between blocks of the metasedimentary rocks. Contact hornfels is common above and at the margins of these intrusions. Regional metamorphism varies from low grade to a chiastolite-staurolite level, but the degree of metamorphism is not a function of the proximity or number of plutons.

There is no notable evidence of thickening or thinning of beds. No crests or troughs of folds can be recognized. It is considered, therefore, that isoclinal folding is not a feasible mechanism. A process called pleated folding is suggested. It is believed that subjacent rocks warmed, dissolved, and formed magma, producing vertical instability, particularly when the region was under compression. This resulted in fragmenting and foundering of the overlying solid sedimentary rocks.

The sinking blocks were thick tabular parallel to the bedding. The direction of flattening of the blocks became oriented perpendicular to the regional compressive direction as the underlying magma was forced between the masses. The process of downbuckling took place at sufficient depth to preserve an overlying relatively undisturbed layer of rocks. The buckled rocks were essentially brittle, and rupture occurred along the lines of buckling, producing a structure comparable to pleats. The repetition or omission of beds depends on the level of foundering.

GRAVITY ANOMALIES AND CRUSTAL STRUCTURE

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The inverse correlation of Bouguer gravity anomalies with elevation that is commonly observed is the basis for the concept of isostasy. To explain this phenomenon, several theories have been advanced involving radically different models of crustal structure. All have the merit that they will effectively account for the bulk of the Bouguer anomaly, but it cannot be claimed that any one of them represents actual crustal conditions. If, however, the results of earthquake and seismic-blast studies on crustal structure are used along with statistical studies to determine the most probable depth above which isostatic compensation is accomplished, it is possible to deduce from the Bouguer anomalies a much more realistic picture of crustal structure. Allowance, however, must be made for the gravitational effect of surficial mass variations related by the local geology. This method of analysis has been tried for several areas and shows that, while in general continents and ocean basins can be classified as distinctive crustal tectonic units, superimposed features such as mountain ranges share no common subcrustal type of "root" system. Further, it is shown that the use of isostatic anomalies for interpreting crustal structure leads to false conclusions. Examples based on gravity results in Europe, North America, and Southeastern Asia are given.

URANIUM CONTENT OF BASE-METAL SULFIDE MINERALS AS AN INDICATION OF THE URANIUM CONCENTRATION IN ORE-FORMING SOLUTIONS

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Determination of the uranium content of pyrite, chalcopyrite, sphalerite, and galena coexisting with uraninite in vein deposits has shown concentrations up to 10^4 times greater than in the same mineral from veins in nonuraniferous districts. Data from 39 deposits in five western States indicate

that the concentration of uranium in the sulfides may provide an index to the uranium concentration in the ore-forming solution.

Alpha-scintillation counts on concentrated, acid-cleaned sulfides are converted to percentage-equivalent uranium, and radioactive equilibrium is confirmed by radium and chemical uranium determinations. The distribution of uranium in the sulfides is studied by means of alpha autoradiographs. Uranium in solid solution and defects is indicated by randomly distributed tracks in contrast to clusters from uraninite in inclusions, grain coatings, fracture fillings, and replacement bodies. The autoradiographs also provide a check on the removal of uranium in grain coatings and fractures by acid leaching. Paragenetic studies are made to check contemporaneity of sulfides with uranium minerals.

A range of uranium content from less than 0.1 ppm to nearly 10^3 ppm has been measured in samples of one mineral from a single deposit. The distribution appears to bear a systematic relation to uranium ore values.

A means of prospecting for favorable areas using activities well below the reach of field counters is suggested.

STRUCTURAL ANALYSIS OF CONCORDANT PLUTONS IN THE GRENVILLE OF SOUTHEASTERN ONTARIO

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In southeastern Ontario, rocks in the Grenville subprovince are chiefly a series of crystalline limestone, paragneiss, and migmatite, in which gabbroic and later granitic masses have been emplaced, in part as concordant bodies with somewhat circular outlines. Each member possessed different competence and reacted differentially to stress; limestone was the least competent.

Statistical analysis of planes of foliation shows at least two directions of movement which were successively dominant: horizontal northwest-southeast and horizontal northeast-southwest.

The northwest-southeast movement gave rise to folds about northeast-southwest horizontal axes. These folds were subsequently overturned to varying degrees but chiefly to the northwest.

The last movement in a northeast-southwest direction caused the rotation of the pre-existing fold axes about either (1) horizontal (northwest-southeast) axes (buckling, folded folds, basins, and domes) or (2) vertical axes.

In the latter case, the results of this rotation varied with the nature of any series which acted as a unit. Diagrams are shown which trace the movements of a special case at Westport, Ontario, where an incompetent series with some competent members reacted in an incompetent fashion, forming vertically plunging cylindrical folds.

The term "vortices" is suggested for these. They formed natural channels for the uprise of magmas and/or granitic emanations and are thus the sites of concordant batholiths.

The "concordant wall-rock structures" of the plutons in this area are therefore pre-granite in origin. Gabbro was emplaced in most of the vortices, followed by monzonite, syenite, or granite.

NATURAL THOLEIITE BASALT—WATER SYSTEM

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Tholeiite basalt (MgO content 10.4 per cent; 1921 flow of Kilauea, Hawaii) was studied at a series of temperatures at 1 atmosphere and at water pressures up to 10,000 bars. At 1 atmosphere the sequence of crystallization was: >1235° all liquid; 1235° olivine in; 1190° pyroxene in; 1170° feldspar in; 1090° *ca* all crystalline (olivine, pyroxene, feldspar, magnetite). At 5000 bars water pressure and

at 750° the basalt had been converted to an amphibolitelike assemblage of amphibole, plagioclase, sphene, and magnetite, with traces of glass. At successively higher temperatures the sequence of changes was as follows: 815° plagioclase out; 875° sphene out; 925° pyroxene in; 975° amphibole out, olivine in; 1090° pyroxene out; 1125° olivine out (liquid + fluid).

The beginning of melting curve of tholeiite basalt (and amphibolite) is 150°–200° higher than that of the minimum melting curve of granite. A comparison of indices of refraction of glass obtained by quenching liquid at the beginning of melting and at the all-liquid stage suggests that the initial liquid is felsic. Since the compositions of most granites lie in or near the low-temperature trough of the "granite" system, much liquid is produced with a small temperature rise above the minimum, whereas only a small amount of liquid is produced from tholeiite basalt at temperatures slightly above the beginning of melting.

MAP OF THE PRECAMBRIAN BASEMENT OF INDIANA DERIVED FROM AEROMAGNETIC DATA

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A regional map of the Precambrian basement surface has been constructed based on the analysis of isolated aeromagnetic anomalies shown on the aeromagnetic map of Indiana compiled from U. S. Geological Survey aeromagnetic county maps. The interpretation methods are basically those described by Vacquier *et al.* (1951). It is assumed that the larger magnetic anomalies are due to lithologic contrasts in the basement complex and that these lithologic units are prisms having vertical sides, plane horizontal surfaces with rectangular cross sections, infinite depth extent, and internal magnetic homogeneity.

In general, the larger features of the computed Precambrian basement surface can be correlated with those of the generalized structure-contour map on top of the Trenton (Ordovician) limestone. The position of the Kankakee and Cincinnati arches and the gradual slope of the basement surface from these major ridges into the Illinois Basin are consistent with the structural pattern of the area. Depths range from 2000 feet in the east to approximately 11,000 feet in the southwest corner of the State. There is also good agreement between the basement-surface map and several depths obtained from well drilling.

The contours of the basement rocks indicate the possible existence of a major northwest-striking ridge in the northeast part of the State that does not appear on the structure-contour map on top of the Trenton limestone. The existence of this ridge is partially confirmed by gravity and seismic data.

ABSTRACTS OF PAPERS SUBMITTED FOR THE MEETING IN TALLAHASSEE, FLORIDA, MARCH 22, 23, 24, 1956

DISTRIBUTION OF TRIASSIC FISH IN THE PIEDMONT OF VIRGINIA

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Triassic fish have been found at several localities in the Richmond Coal Basin. They occur in the coal measures at Winterpock, Midlothian, and Gayton. They occur outside the coal measures at Hallsboro, Vinita, and half a mile south of Manakin. Fish scales have been reported at the Farmville Basin. One fish has been found in the Danville Basin. In the Potomac area Triassic fish have been found at Midlands and near Thoroughfare Gap. The Virginia Triassic fish need careful revision. Recognized families are: Acrolepidae, Catopteridae, Semionotidae, and Coelacanthidae. The following forms are tentatively recognized: *Ptycholepis marshi*, Newberry; *Catopterus redfieldi*, Egerton; *Dictyopyge macrura*, W. C. Redfield; *Dictyopyge* sp.; *Semionotus* cf. *fultus* (Agassiz); *Diplurus longicaudatus*, Newberry; *Diplurus newarki*, (Bryant), Shaeffer. These fish appear to be an endemic freshwater fauna with worldwide affinities. They are similar to the western United States Triassic fish. The genus *Dictyopyge* seems characteristic of the Richmond Coal Basin. *Catopterus* predominates at Midlands, and *Semionotus* at the Millboro Quarry near Thoroughfare Gap. Until the ranges of these forms are better known, it does not seem wise to use them for correlations within the Virginia Triassic.

FREQUENCY OF OCCURRENCE AND SIZE OF THE MAJOR SALT-DOME STRUCTURES OF THE LOUISIANA OFFSHORE OIL PROVINCE

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The Louisiana offshore Miocene oil province has the same basic stratigraphic and structural setting as its onshore counterpart. Oil and gas exploration of this area has now developed enough information regarding frequency of occurrence and size of the major salt-dome structures to enable comparison with the same type features of the onshore Miocene trend.

The implications developed by this comparison are discussed.

REPLACEMENT OF ORDOVICIAN VOLCANIC ASH BY CALCITE

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Bentonites in the lower part of the Martinsburg shale (Ordovician) at Oranda and Fishers Hill, Virginia, are associated with beds and lenses of coarse-grained gray resinous calcite half an inch to 3 inches thick. Thin sections show that the calcite has replaced volcanic ash; shard texture and parallel alignment of biotite flakes are preserved. Broken phenocrysts of feldspar have acquired marked euhedral overgrowths of albite. Freshly broken cross sections of the beds have a characteristic conchoidal fracture caused by numerous curved twin planes in the calcite. Surfaces of the calcite beds in contact with unreplaced volcanic ash (now bentonite) consist of coalescing knobs with concentric internal structure, indicating a concretionary type of replacement. The following observations indicate that replacement preceded deformation and probably preceded alteration of the ash to bentonite: (1) shard texture is preserved in calcite adjacent to bentonite in which shards have been destroyed by alteration and shearing, and (2) veinlets of calcite oriented parallel to major joints sets in adjacent shales cut the replaced ash.

In the Martinsburg shale at Fishers Hill 14 bentonites are partly or wholly replaced by calcite; no similar replacements were noted in near-by bentonite-bearing limestone sections. In view of the

correlative value placed on bentonites, thin coarse-grained resinous limestones in Middle Ordovician shale sections should be carefully examined for ash-replacement possibilities.

OIL-RICH SUNNILAND FORMATION OF FLORIDA, WITH SPECIAL REFERENCE TO THE FORTY-MILE BEND AREA

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Florida's Sunniland formation has become important because it contains oil. More than 4 million barrels of heavy black crude have been produced from Sunniland Field, and more than 33,000 barrels were produced from Forty-Mile Bend Field.

The Sunniland formation is buried below 10,000 feet of sediments and has no surface-oil indications. Therefore deep-oil tests are required. Florida's first deep test was supervised by the late Robert Burns Campbell in 1939. Since that well, 57 oil tests have been drilled, resulting in 16 producers.

Forty-Mile Bend strata, including the Sunniland formation, are defined in terms of rock units.

A *column* is the entire thickness of known rocks in one area—12,000 feet at Forty-Mile Bend.

A *section* is that interval associated with one type of second-order relief feature. At this location the entire column is a basin section.

A *group* is that interval associated with one second-order relief feature. At Forty-Mile Bend the upper 7500 feet was deposited in a basin extending the length of Florida, but the lower 4500 feet was deposited in a basin crossing South Florida.

A *formation* is that interval associated with one major tectonic movement as recorded in a single depositional cycle. The Sunniland formation's upper limit is raised beyond that of Pressler (1947) to include the "Upper Massive Anhydrite". The maximum thickness is 310 feet.

A *member* is that interval associated with one composition. The Sunniland formation has many distinct members, chiefly differing lithologically.

A *bed* is that interval formed under constant physical conditions. The Sunniland formation is thin-bedded and partly laminated.

COMPOSITION OF SEDIMENTS OF THE GREAT BAHAMA BANK

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Samples of bottom cores collected by Preston E. Cloud, Jr., and party in May 1955 on the Great Bahama Bank west of Andros Island have been analyzed for grain-size distribution and mineral content.

The mechanical analyses indicate increasing percentages of very fine sand, silt, and clay-sized particles in a shoreward direction. As much as 90 per cent clay-sized particles were found in sediments collected close to the western shore of Andros Island.

Mineralogical analyses of the sediments by x-ray powder diffraction indicate a predominance of aragonite, with calcite and very small quantities of quartz scattered throughout the area. The clay-sized fractions of the sediments analyzed to date contain over 90 per cent aragonite with small percentages of calcite and quartz. The relative percentage of calcite to aragonite increases in the larger-particle size fractions. The calcite ranges in chemical composition from pure $CaCO_3$ to a calcite containing more than 18 mol per cent of $MgCO_3$.

ANTHRAXOLITE FROM MONTGOMERY COUNTY, VIRGINIA

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Anthraxolite occurs as irregular-shaped fragments, which range up to 3 inches in greatest dimension, in residuum above a brecciated, vuggy, saccharoidal dolomite member of the Cambrian Rome formation and in near-by colluvium along Calhoun Run in Montgomery County, southwestern Virginia. It is black and has a hardness of 2–3, a specific gravity of $1.53 \pm .01$, an ignition temperature

of 640° ± 10°C., a vitreous to oily luster, and a subconchoidal fracture. In attempts to determine possible consanguinity between this anthraxolite and petroleum or coal, chemical, thermal, and x-ray data obtained from the anthraxolite were compared to those same data obtained from anthraxolite proved to have been originally fluid, coals of diverse ranks, lignite, numerous asphaltic materials, paraffin- and asphalt-base oils, heavy petroleum residues, quisqueite, natural graphite, graphite powders derived from coal coke and from petroleum coke, and two unnamed high-carbon compounds found elsewhere in southwestern Virginia. It is concluded that a genetic relationship between anthraxolite, whose occurrence permits more than one interpretation of origin, and coal versus oil cannot be established by the investigated methods.

ILLINOIAN BOUNDARY IN SOUTHWESTERN OHIO AND NORTHERN KENTUCKY

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Earlier workers extended the Illinoian boundary deep into northern Kentucky. The present, more detailed study of pre-Wisconsin glaciation of southwestern Ohio and northern Kentucky suggests that the Illinoian boundary approximately follows the present Ohio River east of Cincinnati but reaches the river in only one area west of the city.

During Illinoian time the ice failed to surmount the divide just west of Cincinnati. However, farther west a narrow lobe pushed south over the topographically lower region bordering the Great Miami River. This tongue extended south at least as far as Petersburg, Kentucky. The present course of the Great Miami south of New Baltimore, Ohio, and that portion of the present Ohio southwest of Cleves, Ohio, originated as an Illinoian marginal channel. The north-south abandoned through valley 1 mile east of Petersburg, Kentucky, was also for a short time a marginal channel. The coarse conglomerate at Split Rock, Kentucky, was deposited by this confined marginal stream at the point where it entered the wide pre-Illinoian "deep-stage" valley or at the terminus of the Illinoian lobe.

The absence of Illinoian till in the tributary valleys of the "deep-stage" drainage of southwestern Ohio and northern Kentucky, a principle recently used by John L. Rich in southeastern Indiana, was employed in establishing this boundary. Further study may show that the morainelike deposits on the upland near Commissary Corners, Kentucky, and the Middle Creek conglomerate just to the south are pre-Illinoian terminal deposits.

EVIDENCE FOR REWORKING OF LYNCHBURG FORMATION IN NORTH-CENTRAL VIRGINIA*

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In north-central Virginia the Lynchburg formation, unconformably over the crystalline core of the Catoctin Mountain-Blue Ridge anticlinorium, consists of a series of metaconglomerates, metasandstones, and metasiltstones. Fragments of the metasiltstones are found in some of the metasandstone beds in Madison, Culpeper, and Rappahannock counties. The fragments are very irregular in size and shape and range from less than 1 inch to more than 2 feet long. They are scattered throughout the beds. The fragments indicate reworking of at least part of the Lynchburg during sedimentation. The mode of occurrence of the fragments suggests reworking by slumping, with the possibility of some turbidity-current activity.

SOLUTION IN BEDROCK AT THE CALHOUN, TENNESSEE, PLANT OF BOWATERS SOUTHERN PAPER CORPORATION

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The Calhoun, Tennessee, plant of the Bowaters Southern Paper Corporation is the largest newsprint mill in southeastern United States. In order to take advantage of several desirable geographic

* Presented with permission of State Geologist of Virginia.

features of the Charleston-Calhoun area, the plant site was located on a belt of Knox dolomite. The many core borings made to explore and treat the foundations for the important mill structures have shown that certain zones are extensively dissolved. A large part of the solution of certain beds of dolomite has been controlled by lithology and developed along the bedding. The extent to which fracturing and recent erosion in the area has determined the size, position, and depth of some cavities has been proven. Some areas are so extensively dissolved that as much as 10 per cent of the mass of the rock has been removed and the deepest cavities in the area are more than 200 feet below the bed of the near-by Hiwassee River.

TECTONICS OF CRYSTALLINE TERRANE OF NORTH CAROLINA

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Recent mapping by the U. S. Geological Survey in the crystalline terrane of North Carolina and adjacent Tennessee provides data for an interpretation of Precambrian and Paleozoic tectonics. Keith's hypotheses are in better accord with this interpretation than are most later ones.

Precambrian plutonism and high-grade regional metamorphism produced gneisses, schists, migmatites, and concordant granitic rocks, which underlie much of the Blue Ridge province, probably most of the inner Piedmont, and some of the northeast Piedmont.

Upon this complex were deposited rocks whose character and age vary regionally. In the southwest, the upper Precambrian Ocoee series was laid down in a local geosyncline; in the extreme northwest, the upper Precambrian Mt. Rogers volcanic group and shelf sediments of the Cambrian; in the east, eugeosynclinal sedimentary and volcanic rocks of early Paleozoic (?) age (slate belt, Kings Mountain belt).

Repeated deformation in the Paleozoic, in part with regional metamorphism and plutonic intrusions, affected both basement and younger rocks, and the basement rocks are polymetamorphic. The major metamorphism of the Paleozoic was early in the era, at least in the Blue Ridge and inner Piedmont. The composite result was the formation of discontinuous and anticlinorial belts of middle- and high-grade metamorphic rocks (Blue Ridge, inner Piedmont, Charlotte) separated and flanked by low-grade rocks.

Granitic rocks of Paleozoic age are mostly two-mica granites and quartz monzonites in the inner Piedmont. The plutonic rocks in and near the slate belt, by contrast, are widely variable hornblende gabbros and diorites, together with quartz monzonites and allied rocks. The silicic plutonic rocks intrude basement rocks; therefore their magmas formed at least partly from subgeosynclinal material. The mafic plutonic rocks may have formed by contamination of such magmas by metavolcanic rocks.

COINCIDENT ROCK ALTERATION AND GROWTH OF K FELDSPAR PORPHYROBLASTS NEAR MACON, GEORGIA

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The unaltered rocks are layered biotite-hornblende-quartz-plagioclase gneisses. In altered areas the plagioclase is sericitized, hornblende and biotite strongly chloritized, and there are pink K feldspar porphyroblasts. All stages are present from unaltered gneiss to partially altered gneiss in which there are microscopic veinlets and small ragged crystal of K feldspar to strongly altered rocks in which all the biotite and hornblende has been converted to chlorite and there are large subhedral K feldspar porphyroblasts. The amount of potassium released by the biotite-chlorite transformation is sufficient for the coincident growth of K feldspar. The petrographic evidence is compelling that a medium- to coarse-grained, pink, granitic rock has been produced by the alteration of fine-grained, dark-gray gneiss.

ENVIRONMENT AND ORIGIN OF THE CRETACEOUS KAOLIN DEPOSITS OF GEORGIA AND SOUTH CAROLINA

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Unsorted sands containing little gravel and much disseminated kaolin constitute the Upper Cretaceous section from central Georgia at least to central South Carolina. Lenses of relatively pure kaolin occur in two areas. The series rests unconformably on crystalline rocks. A gentle unconformity separates the Cretaceous beds from overlying Tertiary beds, and both have been dissected by erosion that began in the Pliocene. Yellow iron-oxide stains and a little bauxite have been formed in the kaolin lenses during this long period of weathering.

The Cretaceous sediments were derived from the crystalline rocks by vigorous erosion on a youthful surface and accumulated in coalescing deltas of coarse feldspathic sands. Most of the iron in the source rocks was taken into solution at the source in mildly acid ground and surface waters and was removed to the sea.

Kaolinite was formed by decomposition of the detrital feldspar in exposed parts of the deltas and, through low-gradient erosion of the sands, collected in ponds formed as cut-off segments of the distributaries. Soft kaolin was precipitated slowly in fresh acidic water. Wave erosion breached some ponds, admitting sea water in which kaolin was coagulated rapidly and is harder. Fish, entering with sea water, provided sulfur for the pyrite that occurs in hard kaolin. As these processes operated, the sea advanced and truncated the series by wave-base erosion.

IMPLICATIONS OF GENTLE ORDOVICIAN FOLDING IN WESTERN VIRGINIA

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Abnormally great thicknesses of Paleozoic sediments in the Massanutten and Greendale synclines in western Virginia indicate that gentle folding accompanied sedimentation. This folding was underway in Ordovician time. The major disconformity between Lower and Middle Ordovician limestones in the Valley and Ridge province is locally absent. An example is the conformable and apparently gradational relationship of these limestones near the depression of a major syncline in the Shenandoah Valley where the basal Middle Ordovician limestone is abnormally thick. This is of particular significance because on the crest of an adjacent anticline the contact is sharp, and the basal Middle Ordovian limestone is abnormally thin.

Re-examination of evidence bearing on the "Taconic disturbance" in eastern Pennsylvania indicates at most mild deformation. Recrystallization and cleaving of the Martinsburg shale certainly did not occur prior to burial beneath Silurian and younger sediments. The metamorphism appears to have been the result of the deformation that produced slaty cleavage in some of the near-by Devonian shales.

The recrystallization and cleavage exhibited by the slates formed from Upper Ordovician shales at Arvonia, Virginia, suggest that deposition in the Piedmont continued into at least Middle Paleozoic time. The metamorphism of the shales may not have occurred before Late Paleozoic time.

The structural features (and some stratigraphic features) of the Paleozoic rocks of Virginia appear to be not the result of periodic disturbances but the results of nearly continuous deformation throughout much of Paleozoic time.

LOWER CRETACEOUS HEAVY-MINERAL SUITES FROM THE NEW JERSEY AND PENNSYLVANIA SUBSURFACE

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The oldest fossils from the New Jersey Coastal Plain occur in the basal Upper Cretaceous Raritan formation. The presence of Lower Cretaceous sediments in the subsurface of New Jersey has been suggested by several workers, but lack of fossils has prevented definite correlations.

Recent heavy-mineral studies in the Coastal Plain in Delaware and Maryland have shown that the Cretaceous formations there can be correlated on the basis of heavy minerals. Heavy-mineral suites such as those observed in the Lower Cretaceous of Delaware and Maryland have been obtained from shallow depths in New Jersey and Pennsylvania wells. The provenance, relation to basement configuration, and paleogeographic and stratigraphic implications of the heavy-mineral suites are discussed.

STRATIGRAPHIC DISTRIBUTION OF IRON DEPOSITS IN THE SOUTHEASTERN UNITED STATES

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Iron deposits occur in exposed rocks of nearly every geologic period in the southeastern United States. In some cases the age of the iron minerals differs greatly from that of the associated rocks. The deposits consist of four major types: (1) limonites (brown ores), (2) hard hematites and magnetites, (3) red ores (Clinton), and (4) carbonates. In Precambrian schists and gneisses are found a great number of magnetite, martite, and specular hematite deposits, as well as a few brown ores. Limonites and a few hematite deposits related to quartzites and dolomites are found in Cambrian rocks. In Ordovician rocks, brown ores occur, and replacement magnetites are reported. Clinton (Silurian) hematites have long been ores for Alabama steel industries. Devonian brown ores (Oriskany) were once the source of iron ore in Virginia and West Virginia. On top of Mississippian rocks as well as in overlying Cretaceous rocks in Alabama and Tennessee is a series of brown ores. In Pennsylvanian rocks are siderite beds which once supported small furnaces in West Virginia. Small occurrences of limonitic sands have been reported in the Triassic rocks of North Carolina and in the Tertiary formations of South Carolina and Alabama. Siderite concretions in Tertiary formations in Mississippi have been explored recently. Considerable work remains to be done to evaluate the age of the iron deposits in respect to the age of the rocks in which they are found.

RECENT INVESTIGATIONS OF CLAYS AND SHALES IN KENTUCKY

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Recent geologic investigations in Kentucky have indicated large reserves of clays and shales which have a variety of uses in the clay industry. These deposits are widely distributed and range in age from Silurian to Tertiary.

The ball clays of the Holly Springs formation (Eocene) of the embayment portion of western Kentucky are well known as outstanding raw materials for the manufacture of chinaware products. Core drilling by operating companies and spot investigations by the Kentucky Geological Survey have located substantial reserves. Tests by the Electrotechnical Laboratory, U. S. Bureau of Mines, Norris, Tennessee, have revealed that the Porters Creek clay, a fuller's earth type, in this part of Kentucky is better than the chemical oil standard for absorbent clay.

Many underclays and shales of Pennsylvanian age in both the Eastern Interior Basin and Appalachian Plateau areas of Kentucky are suitable for brick, tile, sewer pipe, flue linings, stoneware, and refractories. Also some shales of Pennsylvanian age possess bloating characteristics which would make them highly desirable for the manufacture of light-weight aggregates.

A number of Mississippian shales are suitable for brick, tile, and other heavy clay products. The New Providence shale, in places, is also satisfactory for the manufacture of light-weight aggregate.

Silurian shales (Estill formation) along the eastern rim of the Outer Bluegrass region show some possibility for structural clay products.

PARAGNEISSIC FORMATIONS OF NORTHERN VIRGINIA

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Paragneiss is defined as a metamorphic granitic rock reconstituted from clastic sediments without fusion and without the addition of extraneous granitic material. Earlier workers, notably Arthur

Keith, have claimed that a large part of the Carolina gneiss and similar rocks in the Southeastern States originated in this manner. This interpretation is shown to have a wide application.

Chemical, petrographic, and other methods heretofore used to identify metasedimentary rocks are reviewed. The present investigation is based upon a study of the accessory minerals of granitic gneisses and schists, obtained by panning their saprolites. Eight diagnostic criteria are proposed and discussed. The most significant of these is the resistance of zircon to recrystallization, thus preserving its original size and detrital shape.

The hypersthene granodiorite, or Pedlar formation of Bloomer and Werner (1955), is a sedimentary gneiss. Similarly the Marshall granite comprises mainly metasedimentary gneisses. Even the Catoctin greenstone contains some paragneiss and a palingenetic granite of sedimentary origin. The Lovingston granite gneiss in Culpeper County is a paragneiss with an interbedded monazite-bearing quartzite. At its type locality near Lovingston, this formation appears to be of sedimentary origin and is believed to be a paragneiss. Other formations in Virginia recognized as metasedimentary include granitized gneiss of the Wissahickon, the Baltimore gneiss, and the Lynchburg gneiss. Formations less securely determined as metasedimentary are the Columbia granite of Jonas (1932), the Grayson granodiorite gneiss, and part of Redoak granite of Laney (1917). Other granitic rocks of gneissic habit are under investigation.

STRATIGRAPHY OF PLEISTOCENE TERRACE DEPOSITS IN VIRGINIA*

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Three new post-Yorktown formations underlying Pleistocene terraces have been recognized on the Virginia Coastal Plain south of the James River. Two of these new formations underlie both the Sunderland and the Wicomico terraces. The other new formation underlies the Dismal Swamp terrace and possibly the Princess Anne terrace. A Sangamon age is indicated for the Wicomico terrace because complete deglaciation at the present time would submerge the Wicomico terrace, and there is no evidence for a major interglacial stage since the Wicomico terrace. A Sangamon age for the Wicomico terrace is not unreasonable because Leverett has traced Illinoian gravels into the Wicomico terrace in Pennsylvania. The same formation underlies both the Wicomico and Sunderland terraces in Virginia, and the Sunderland is interpreted as the subaerial equivalent of the Wicomico terrace and thus of Sangamon age. Terrace deposits cannot universally be given the formation name of the terrace surface they underlie because in Virginia the same formation underlies both the Sunderland and Wicomico terraces. The Dismal Swamp terrace is interpreted as forming in a tidal lagoon, separated from the open ocean by a chain of barrier islands, comparable to the tidal flats that exist today east of the eastern peninsula of Virginia.

STRUCTURE AND GEOLOGY OF THE VIRGINIA PIEDMONT

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The major structural features of the Piedmont of Virginia are a great anticlinorium extending from the Blue Ridge to Southwestern Mountain in a general northeast direction. The core of the anticlinorium is composed of a Precambrian Basement Complex, known as the Lovingston gneiss. In ascending order above the Basement Complex are the Rockfish conglomerate, the Lynchburg gneiss, the Swift Run formation, and the Catoctin greenstone. East of this great anticlinorium a great synclinorium is bordered on the west by the Lovingston gneiss and on the east by an outcrop of similar rocks occurring on the south side of the Roanoke River, a few miles west of the Fall Line.

This great synclinorium is composed of four synclinal belts and three anticlinal belts. The axis of the synclinal belts from west to east are (1) the Everona limestone of Ordovician age, (2) the Arvonia slates of Ordovician age, (3) the Virgilina-Quantico syncline of Cambro-Ordovician age, and (4) the Gasburg syncline containing volcanics of Precambrian age.

It is considered that much of the granitization and folding in the Piedmont took place at the close

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of the Ordovician period and that the pegmatite dikes occurring in belts throughout this area are of the same age. There are several granite stocks of late or post-Paleozoic age.

The oldest major faults have a northeast-southwest direction and are high-angle thrust faults. Northwest-southeast normal faults cut and displace northeast normal faults. High-angle reverse faults displace Pleistocene gravel deposits 5–10 feet.

Several Triassic basins partly obscure older structures.

TREE CURVATURE RELATED TO SLOW MASS WASTAGE

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The apparent displacement of objects on soil-covered slopes is used to support the concept of slow mass-wasting processes, which are included under the term soil creep. While tipped or displaced cultural features—*i.e.*, fences, retaining walls, telephone poles—are used as evidence of the downslope progress of surficial materials, the most-emphasized and unique manifestation suggested for slow flowage is the curvature of tree trunks. In the search for evidence of soil creep, the more logical deforming agents for this feature in trees are entirely overlooked, and, although the problem is certainly as much botanical as geological, the physiology of tree growth has been ignored.

This paper discusses the type of curvature resulting from an assumed concomitant tree growth and soil creep, and also presents other causes leading to tree curvature. It is concluded that the proper tree curvature is rarely, if ever, observed, and that alternate explanations are probably more valid. Because of the widespread dependency upon tree curvature, soil creep undoubtedly needs re-evaluation as a geomorphic process, or the term needs redefinition.

PRE-ILLINOIAN AGE OF UPLAND TILL IN SOUTHEASTERN INDIANA, SOUTHWESTERN OHIO, AND ADJACENT PARTS OF KENTUCKY

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A 1953 winter flight over a southeastern Indiana area where flattish upland remnants between valleys tributary to the Ohio River are covered by till commonly dated Illinoian revealed a striking lack of glacial deposits in the valley bottoms or along their sides except close to Ohio River, where flat-topped terrace remnants are conspicuous.

Ground examination revealed no glacial material in the valleys below a level roughly 100 feet beneath that of the till-covered upland and showed the valley-mouth terrace materials to be deltas built into lakes formed in the tributary valleys when the latter were blocked by rising outwash trains in the Ohio and lower Whitewater valleys. These deltas grade from coarse outwash gravels, where the tributaries join the main valleys, into clays up-stream.

Previous to Illinoian glaciation, the valleys of the region had been cut to approximately 100 feet below present low water—the so-called "deep stage".

At and east of Cincinnati, Illinoian till lies low in these "deep-stage" valleys, as it does also in the lower Whitewater-Old Miami-Ohio valley at least south to Cleves and probably several miles farther. Lack of such till in the tributaries entering the lower Whitewater and the Ohio in southeastern Indiana and in Kentucky from north of Lawrenceburg to near Madison or beyound indicates that ice never covered that area after the "deep-stage" valleys were cut. Thus the upland till in this entire area must be pre-Illinoian—presumably Kansan—and the Illinoian boundary west of Cincinnati needs drastic revision.

GEOMORPHIC EVIDENCE BEARING ON THE TECTONICS OF THE CUL-DE-SAC—HOYA DE ENRIQUILLO "GRABEN" OF HAITI AND THE DOMINICAN REPUBLIC

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A flight from Port-au-Prince, Haiti, eastward through the classical "graben" of Haiti-Santo Domingo gave opportunity for recording by oblique aerial photographs many features of the geomor-

phology of the graben and its surroundings which throw light on the tectonics of the graben and on its geomorphic development.

Available maps have been utilized for determining the flight line, the position of each camera station, and the orientation of each photograph. The literature has been searched for pertinent ground observations.

North of the graben, an old-age upland, probably produced partly by stripping of limestones, bends abruptly down into the graben, with probable faulting along much of the downbend, but nothing visible in the photographs indicates great recency of the faulting.

The photographs of the south wall of the graben also reveal an old-age surface. This has been developed largely on limestones, but the photographs do not reveal any direct rock control of surface forms. This old-age surface descends to the bottom of the graben trough in a series of steps produced partly by warping, but dominantly by faulting parallel to the graben wall, much of it apparently extremely recent. Since this surface must have been brought to completion while near sea level, yet now stands at more than 5000 feet in the highland south of the graben, it is suggested that the graben may have been produced by recent upfaulting and upbowing of the mountains south of the graben—a compressional feature rather than dominantly by downsinking as a result of tensional forces.

RECENT STUDIES ON THE RARITAN FORMATION OF NEW JERSEY AND LONG ISLAND

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Through the co-operation of Transcontinental Gas Pipe Line Corporation, the writer has examined a series of cores obtained from various parts of southern New Jersey. Special attention has been paid to those from the Raritan formation. Although this formation is generally nonmarine in outcrop except for a small fauna near Sayreville, New Jersey, the subsurface portion of the formation has revealed a fairly rich marine fauna. To date, a fauna of 31 species has been identified of which 11 are new. The closest relationship is with the Woodbine formation of Texas. A few species known from younger Cretaceous formations (Monmouth-Matawan) are also present in the core samples suggesting that some species may have persisted in deep water throughout much of Late Cretaceous time. The Raritan fauna is marked by the presence of a new genus of Bryozoa; this is one of the few records of Bryozoa from the Cretaceous of North America.

Preliminary work on heavy minerals from outcrops and well cuttings on Long Island suggests that some material previously assigned to the Cretaceous may actually be Pleistocene.

STRATIGRAPHIC SIGNIFICANCE OF FORAMINIFERA FROM AN OUTCROP OF THE TUSCALOOSA FORMATION AT CHERAW, SOUTH CAROLINA

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An outcrop at Cheraw, South Carolina, furnishes the first microfauna recognized from outcropping basal Cretaceous strata east of the Mississippi. The outcrop, composed of pyritic black, carbonaceous clay and interbedded coarse sand, lies near the base of the Tuscaloosa formation, at an elevation of about 85 feet and about 45 feet above crystalline basement rocks. The Tuscaloosa formation, as known in the subsurface of the Carolinas, has been considered equivalent at least in part to Eagle Ford and Woodbine strata of the Gulf Coast; its extension into South Carolina and North Carolina is based largely on stratigraphic position and lithology. Overlying the Tuscaloosa is the Black Creek formation, of Taylor and Austin age.

The following Foraminifera occur in the outcrop at Cheraw: *Eouvigerina* sp., *Pseudovigerina* sp., *Globigerina* sps., *Proteonina* sp., *Pelosina* sp., *Stilostomella* sp., and *Globulina ?* sp. None of the fossils has been recognized in comparative faunas from Atlantic and Gulf Coast deposits. The assemblage represents a scarce, depauperate fauna, significant because of the stratigraphic implications arising from its geographic location. The fauna, although not diagnostic, appears to be somewhat older than that found in strata of known Austin equivalents of the subsurface of North Carolina and is, therefore, believed to indicate strata of either basal Austin or Eagle Ford and Woodbine age.

The closest known fossiliferous strata of Cretaceous age are plant-bearing beds at Middendorf, 20 miles southwest and stratigraphically higher than the Cheraw locality. The flora at Middendorf reportedly contains 25 species in common with the Black Creek of North Carolina and 26 species in common with the Tuscaloosa of Alabama.

CRETACEOUS, PALEOCENE, AND LOWER EOCENE GEOLOGIC HISTORY OF THE UPPER MISSISSIPPI EMBAYMENT

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Subsurface data show that the Upper Mississippi Embayment record of Cretaceous, Paleocene, and Lower Eocene deposition is a single complex sedimentary cycle.

The cycle began with Cretaceous deposition of nonmarine Tuscaloosa restricted in areal extent. Marine advance and depositional limits reached a maximum in the Paleocene with the Porters Creek clay which once generally extended beyond the Embayment limits. Deposition ended in the Early Eocene with nonmarine Wilcox beds now restricted to the subsurface near the Embayment axis. An interval of uplift and erosion resulting in marked truncation followed to complete the cycle.

Overlying Middle Eocene Claiborne beds overlap all Lower Eocene Wilcox and part of the Paleocene Midway all around the upper end of the Embayment north of the Tennessee-Mississippi border.

Within the above major sedimentary cycle five advances and regressions of the sea are recorded. These are illustrated by stratigraphic cross sections and a series of paleogeographic maps. The pre-Claiborne truncation pattern is illustrated by a paleogeologic map.

The pattern of basal onlap with the sedimentation limit extending to a maximum in the Paleocene is the result of negative tectonic behavior of the Embayment depositional area. Above the Paleocene, limits of preservation of sediments are increasingly restricted toward the Embayment axis, but this situation is the result of uplift after deposition.

Transgressions and regressions of the sea result from interplay between rate of subsidence and rate of sedimentation and perhaps also eustatic sea-level change, factors which are controlled by events which occurred beyond the Embayment limits.

STRUCTURAL RELATIONSHIP OF THE VALLEY AND RIDGE AND CUMBERLAND PLATEAU IN THE SOUTHERN APPALACHIANS

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Recent data from detailed geologic mapping of the Cumberland Plateau and adjoining parts of the Valley and Ridge in Tennessee and from deep drilling on the Plateau have revealed previously unreported structural features which show that the low-angle thrusting concept is correct for this area. Integration of these data with previously reported information indicates that this same type of deformation occurred throughout the Valley and Ridge province of the Southern Appalachians.

Low-angle thrusting involves rocks of much of the Cumberland Plateau. The Pine Mountain and Cumberland Plateau faults are low-angle thrusts, and recent drilling has demonstrated that the Sequatchie anticline results from a thrust; all these structures have their roots to the southeast beyond the Plateau. These faults extend along the west side of the Valley for 400 miles from Virginia to Alabama.

Detailed geologic mapping proves that the seemingly detached masses of Pennsylvanian rocks in the Valley east of the Plateau in Tennessee are fensters and the overriding thrust plate is apparently an extension of the Pine Mountain fault. Although seemingly anaomalous in position, these overridden masses of Pennsylvanian rocks lie at an elevation to be expected from the extension of the normal southeast dip of the same beds in the Cumberland Plateau west of the disturbed Cumberland front, and Pennsylvanian beds buried by thrusting extend into the Valley a considerable distance.

Thus the Cumberland Front rather than the fensters is anomalous, and the structures of the Cumberland Plateau and the Valley and Ridge merge.

LAFAYETTE FORMATION AND CAROLINA BAYS

Stephen Taber
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The Lafayette formation typically consists of a poorly sorted, red, clayey sand, with much gravel in the Piedmont and upper Coastal Plain and some small pebbles near the coast. Clay and iron oxides serve as a binder so that deep excavations have nearly vertical walls after a century of exposure. The formation was deposited as a veneer that has not appreciably changed the topography. Deposition resulted from a rapid subsidence followed by uplift of the land. Water collected in depressions on the irregular uplifted surface, and leaching removed binding material. During long periods of drought the water table was lowered, and ponds dried so that the winds could remove loose material. Transport of coarse sand was checked by surrounding vegetation and was deposited near the rim of depressions, while fine sand and dust were widely distributed. The coarse quartz sand of the bay rims is entirely different from any formation in the Coastal Plain. It supports a very sparse vegetation and therefore is prominent on aerial photographs.

CAROLINA COASTAL PLAIN RIDGES AND BARRIER BEACHES

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Along the Carolina coast a rapidly rising sea is invading land protected by vegetation, beaches are narrow, and most active sand dunes are small. At Myrtle Beach State Park a stabilized dune ridge parallels the beach about 200 yards inland. Back of it the land is low with fresh-water ponds and swamps but rises gradually and then more abruptly to 20 feet elevation. This scarp marks the limit of marine encroachment during the Optimum Climate, and the dune ridge was formed during retreat when a broad beach was exposed to wind action. In places the sea is cutting into stabilized dunes and some dune areas are separated from the mainland by tidal channels.

Myrtle Ridge, roughly paralleling the coast 1.5 miles inland, consists of sand similar to that in coastal dunes. Geology, pollen analyses, and radiocarbon dating indicate that Myrtle Ridge was formed as the sea receded at the beginning of Wisconsin time. Toward the northeast Myrtle Ridge approaches the coast, and near Little River it begins to form barrier beaches which near Cape Lookout diverge from the mainland to form the Outer Banks that enclose Pamlico Sound.

CROSS-BEDDING VECTORS AND ISOPOTENTIAL LINES

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Cross-bedding directions are vectors in three-dimensional space. For map purposes the third (vertical) dimension may be ignored, as is commonly done, or may be expressed by means of isopleths or form lines. In the two map dimensions, cross-bedding vectors, as a general rule, may be resolved into two components, littoral and channel.

Littoral vector components may be used to establish the direction—but not the spacing or absolute values—of form lines which represent, among other things, the general configuration of the land or sea-bottom slope. Channel-vector components may be used to establish the direction of *velocity field* or *flow* lines, which are orthogonal to the isopleths. Channel-vector components also may be used to approximate the spacing of the form lines, which then become isopleths, or isopotentials, having no absolute numerical base. This is predicated on the fact that the intensity of a field is inversely proportional to the distance between isopotentials. The intensity may be estimated by evaluating at each locality the ratio of channel measurements to toal measurements.

The resulting isopotentials represent many factors, probably including bottom configuration, prevailing wave and current patterns, and eustatic and tectonic adjustments. It is thought, however, that they are first approximations to submarine contours and therefore are of interest in making paleogeographic reconstructions. A cross-bedding study of the Pennsylvanian sediments of Alabama,

Georgia, Tennessee, and Kentucky reveals a shore line having a north-south trend, rather than being parallel to the present strike or the isopach lines.

GEOLOGY OF THE POSTOAK WINDOW, TENNESSEE

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Postoak Valley, Roane County, Tennessee, is an elongate northeast-southwest window exposing middle Ordovician to Mississippian rocks surrounded by Cambrian strata. The window is eroded through an anticline of allocthonous Rome sandstone in the Chattanooga fault belt. The fault plane dips northwest and southeast away from the axis of the window. Thrust faulting westward beyond the axis overturns and cuts off the anticline at either end of the window. A subsidiary fault exists, at least locally, immediately northwest of the anticline. The writer suggests that the window is evidence of a post-thrust folding of a thrust-fault plane which emerges along the front of the Cumberland Escarpment where Pennsylvanian rocks have been downfolded beneath overthrust Valley and Ridge sediments.

ABSTRACTS OF PAPERS SUBMITTED FOR THE MEETING IN RENO, NEVADA, MARCH 29–31, 1956

CORDILLERAN SECTION (GSA), PACIFIC COAST SECTION (PS), AND SEISMOLOGICAL SOCIETY OF AMERICA

IGNEOUS INTRUSIONS IN THE NORTHEASTERN CASCADES OF WASHINGTON

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An area of more than 1000 square miles, immediately south of the Canadian boundary along the Cascade Crest and eastward, consists of folded and faulted late Jurassic, Cretaceous, and early Tertiary (?) marine and continental sedimentary rocks and volcanics. These rocks have been intruded by six stocks and two small batholiths. Two of these intrusions have been previously described—the most northerly, the Castle Peak stock, by Daly and the most southerly, the Golden Horn intrusion, by Misch. Although differing somewhat in composition, in the immediate structural settings, and probably in time of injection they have in common sharp contacts with no evidence of assimilation, consanguineous dike retinues; all but one, the Fawn Peak stock, show evidence of their forcibly shouldering aside the country rock to make room for themselves. The two largest intrusions have border facies of miarolitic biotite granite surrounding interiors of granodiorite. The smaller stocks have chilled dioritic shells around quartz dioritic to granodioritic cores. Regionally, the folded sediments and their late intrusions are faulted down between two great crystalline complexes—the Chelan-Skagit schists, gneisses, and migmatites to the west and the Okanogan migmatite-granitic complex to the east.

PROGRESS REPORT ON INSTRUMENT RESEARCH

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A tubeless amplifier consisting of a light source, a galvanometer, and two cadmium sulfide photocells has been developed for use in seismographic recording. The power gain, of the order of 10^9, is sufficient to operate ink, hot stylus, or magnetic tape recorders directly from electromagnetic seismometers. Owing to its low power consumption, the amplifier is particularly well suited for use in portable seismographs.

The transistor-operated variable-discriminator transducer described in a previous paper has been installed on a vertical-component pendulum of 13 seconds period. The response characteristics of this combination are almost identical with those of the Milne-Shaw horizontal-component instruments.

Vacuum-tube decade counters have been substituted for the Wang magnetic counters in the quartz-crystal clock.

GEOLOGY AND DISTRIBUTION OF HYDROTHERMALLY ALTERED VOLCANIC ROCKS WHICH ARE POTENTIAL SOURCES OF CERAMIC RAW MATERIALS

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As many American manufacturers of whiteware, porcelain, and ceramic tile must bring in essential raw materials over long distances, there is considerable incentive for finding new, closer sources of raw materials. About four-fifths of the raw material for Japan's flourishing chinaware industry is

supplied from toseki or chinastone deposits. These chinastones consist of various combinations of such minerals as sericite, quartz, alunite, kaolinite, and some other clay minerals and have been derived chiefly from volcanic rocks of rhyolitic or dacitic composition. Similar rocks are widely distributed among volcanic piles in many parts of the world but have not been extensively exploited elsewhere than in Japan. Hydrothermal alteration, a fundamental part of many volcanic episodes, commonly is accompanied by release of large volumes of silica, and these silicified rocks commonly serve as guides to location of economic deposits. Economic deposits are most extensively developed in rocks originally of high permeability, notably along strong shear zones. Thermal and petrographic studies of American rocks similar to the Japanese chinastones indicate that the commonest end products of the hydrothermal process consist predominantly of sericite-quartz, kaolinite-quartz, alunite-quartz, or pyrophyllite-quartz mixtures, but minerals apparently transitional between clays and micas have been noted in quantity in some deposits. Some beneficiation may be necessary to eliminate a small amount of coloring matter, chiefly iron and manganese, commonly present in the hydrothermal deposits. The occurrence, ceramic properties, and beneficiation procedures are described.

ROLE OF GEOLOGY AT THE HANFORD WORKS, WASHINGTON

R. E. Brown

The disposal of liquid radioactive wastes to the ground at Hanford, originally a temporary and expedient means of handling selected wastes, has become an increasingly acceptable and respected, as well as economical means of underground "waste storage," owing to the value of the geological and hydrological factors, proven during the 10 years of disposal experience.

The Hanford area lies within the Pasco Basin, a topographic and structural basin in south-central Washington. The region is underlain by the Yakima basalts and related volcanic units to depths probably in excess of 5000 feet. A series of unconsolidated sedimentary formations up to 1200 feet thick overlies the bedrock volcanics and provides the media for waste storage. Waste solutions and ground waters are traced through these formations, and their behavior evaluated with respect to the geologic conditions. Waste-disposal facilities are located with respect to these conditions to provide the maximum feasible ion-exchange capacity and the longest practicable time of travel to points of use of the ground waters. Microgeologic and microhydrologic concepts, developed through such studies, reinforce the classical methods and have permitted the discharge to the ground of greatly increased volumes and total amounts of radioactive materials.

TECTONIC HISTORY OF THE ROWLAND QUADRANGLE, NORTHERN ELKO COUNTY, NEVADA

Kent Bushnell
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The major rock units exposed in the Rowland quadrangle are lower Cambrian (?) quartzites, probable mid-Paleozoic argillaceous and calcareous formations grouped into an eastern and a western facies, an upper Pennsylvanian limestone with a thick basal conglomerate member, two granitoid stocks tentatively dated as upper Cretaceous, and andesitic and rhyolitic tuffs and flows extruded during the mid-Tertiary.

Three periods of orogeny are recognized. The first is dated as late Mississippian to early Pennsylvanian. The Pennsylvanian conglomerate and limestone lay unconformably on units of the eastern and western facies. The available evidence is not conclusive, but it does suggest that thrusting, correlated with that in central Nevada, brought the two facies into juxtaposition.

A second orogenic period is dated as late Mesozoic to early Cenozoic. Deformation included thrusting of the Pennsylvanian limestone, large-scale folding and faulting, emplacement of the stocks mainly by the forcible intrusion of fluid magma, and continued faulting with the development of a tear fault which separates the quadrangle into two structural blocks. Also associated with this period is the development of a major east-west structural trend along the Nevada-Idaho border.

A third orogenic period during the mid-Tertiary consisted of two types of deformation, Basin and Range block faulting and Snake River Plain downwarping. The southern limit of the Snake River downwarp coincides with the east-west trend developed in the preceding orogenic period.

DEPTH OF FAULTING

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Reid's formula connecting energy arriving at a point on the earth's surface with depth of fault break is modified so that the energy is that per unit area of earth's surface. Dip of the fault is also introduced. Following Gutenberg, intensity is then expressed as a function of acceleration and period. The assumption is made that the maximum acceleration accompanies longer periods at greater distances. The law of increase of period with distance is

$$\log_{10} \frac{T}{T_0} = 1.3\, x^2\, 10^{-6}$$

which holds only out to $x = 600$ km. This seems necessary to make the observations of variations of observed intensity with distance agree with the computed.

The intensity at the fault is very important in the computations. Agreement is reached for the following:

Earthquake	I_0	Depth of Break
San Francisco 1906	9	20 km
Imperial Valley 1940	10	15 km
Fairview Peak-Dixie Valley 1954	9.5	23 km

RESERVOIR LOADING AND LOCAL EARTHQUAKES IN THE LAKE MEAD AREA

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A continuous record of felt and recorded local earthquakes in the vicinity of Hoover Dam has been maintained since 1938.

The record of felt earthquakes began September 1936, somewhat more than a year after the reservoir began to fill, and since that time the pattern of felt and recorded earthquakes followed fairly closely seasonal fluctuations of water loads in the reservoir. Energy content in the earthquakes, with one or two exceptions, has also followed seasonal load fluctuations. Evidence from three Levels surveys indicates that some of the earthquakes may have been caused by a downward settling of the intermontane valleys containing the lake against more stable land masses—a resumption, because of the added load of the newly created lake, of Pliocene or later activity. If this idea is correct, this renewed activity had discontinued by the time of the second Levels survey in 1941 when the reservoir was nearly full. However, since 1941, seasonal load fluctuations may have had a triggering effect on local earthquakes.

PERMIAN PHOSPHATE DEPOSITS IN NORTHEAST NEVADA AND ADJACENT PARTS OF IDAHO AND UTAH

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A phosphatic shale of Permian age, about 680 feet thick, underlain by cherty dolomite and overlain by about 2500 feet of chert and limestone, crops out in the Leach Mountains 10 miles west of Montello, Nevada. The chert and limestone are overlain by calcareous siltstone similar to that of

the Dinwoody formation of Triassic age. The shale, chert, and carbonate rock are partial correlatives of the Phosphoria, Park City, and Gerster formations of adjoining areas.

Reconnaissance during 1955 in northeastern Nevada and adjacent parts of Idaho and Utah, guided partly by information obtained from oil companies, resulted in the discovery of about 75 miles of outcrop of rocks of Phosphoria age not previously reported. These rocks grade from chert, cherty mudstone, and subordinate phosphatic shale in south-central Idaho to chert, carbonate rock, and phosphatic shale in northeastern Nevada and northern Utah, and to carbonate rock and sandstone in southeastern Elko County, Nevada, and west-central Utah.

Phosphate beds in these outcrops have not been adequately explored, but the thickest and richest beds appear to be in the Leach Mountains and vicinity. There a 3-foot phosphorite at the base of the shale contains 28.7 per cent P_2O_5, and a 10-foot zone of interbedded calcareous phosphate rock and calcareous mudstone 80 feet above the base contains 18 per cent; the lower 5.5 feet of the upper zone averages 20.5 per cent P_2O_5. Regional facies relationships indicate that if better deposits exist in this tri-state area they are probably to be found north or east of the Leach Mountains.

VOLCANIC DOMES OF THE COSO RANGE, INYO COUNTY, CALIFORNIA

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A group of volcanic domes of Quaternary (?) age rest upon a granitic complex of late Jurassic age in the southern part of the Coso Range, western Inyo County, California. Moderately violent volcanic eruptions preceded the emplacement of the domes and resulted in the development of low cones and bedded deposits of pumice lapilli tuff. The internal structure of the domes indicates that they were emplaced as upheavals of molten viscous lava that solidified in the low cones to form domes. At two of the domes the lava flowed beyond the confines of the lapilli rim of the cones and developed short coulees. The domes are composed principally of gray pumiceous perlite which locally grades into black obsidian.

SIZE DISTRIBUTION OF ROCK TYPES IN STREAM GRAVEL AND GLACIAL TILL

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Studies of gravel from the Colorado, Green, Kansas, and Missouri rivers as well as from small streams near Kansas City demonstrate that the percentage of a given rock type in stream gravel varies with the size distribution of the particles in the sample. The variations are large and commonly account for differences of 40 per cent or more between lithologies of unsized samples. Accordingly, pebble counts of stream gravel should utilize restricted grade sizes determined by sieving or other methods of accurate size measurement.

Studies of the coarse fraction of Kansan till from northwestern Missouri and northeastern Kansas indicate that the lithology of till also varies with the mean diameter of the particles in the sample. The variations are, however, less than one-fifth as great as the variations found in stream gravel. This contrast in size-lithology variation may represent a fundamental difference between till and stream gravel. Some restriction of grade size should be made in pebble counts of till. Sorting by visual estimation of size is probably accurate enough for most routine descriptions of till.

BEHAVIOR OF RAYLEIGH WAVES NEAR CORNERS

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Rayleigh waves at a corner are both reflected and transmitted. The coefficients of reflection and transmission as well as the phase shift are experimentally determined for various angles. Very large variations are found in certain cases for a small angular change (*e.g.*, energy reflected at a 90-degree

corner: ca. 10 per cent, at a[illegible]ee corner ca. 1 per cent). The excess energy is believed to be radiated as *P* and *S*. This [illegible]ave consequences for the phenomena occurring at continental boundaries.

MICROSEISMS NEAR LAKE KIVU, EASTERN BELGIAN CONGO

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Squalls on Lake Kivu, Eastern Belgian Congo, produce short-period microseism (ca. 1.1 sec.) on the "Benioff" vertical seismograph about 10 km from the lake. It is not known whether the cause is the pounding of the waves on the shore or the variations of pressure on the bottom of the lake, but it is not the wind at the station. The phenomenon occurs about 100 times a year.

STABILITY RELATIONS OF CINNABAR AND METACINNABAR

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Cinnabar, red HgS, and metacinnabar, black HgS, occur together in some mercury ore deposits. Previous experimental work led investigators to regard cinnabar as the only stable crystalline phase of HgS and metacinnabar as metastable at all temperatures to the volatilization temperature, 580°C. The writers' investigation, however, has indicated that above 344 ± 2°C metacinnabar is stable and that below 344°C cinnabar is stable. The cinnabar-metacinnabar inversion temperature at one atmosphere pressure was determined by use of apparatus designed by Dickson and Kennedy which establishes and maintains controlled temperature gradients. Cinnabar was heated 4 days in a glass tube along which existed a temperature gradient of 10°C per inch. Temperatures were measured by thermocouples at known positions along the tube. The boundary between red and black HgS was located visually within ±0.1 inch; the location of the boundary was further confirmed by x-ray examination.

Metacinnabar, made by heating pure HgS, inverts rapidly to cinnabar on cooling. The presence of less than 0.5 per cent FeS_2 or ZnS, however, retards the inversion and lowers the inversion temperature. Addition of FeS_2 lowers the inversion temperature at least 30°C, and addition of ZnS lowers the inversion temperature at least 100°C.

Studies by the authors of metacinnabar-cinnabar textures in rocks from mercury ore deposits in California and Nevada demonstrated that metacinnabar is generally older than cinnabar, as would be expected of the high-temperature form of HgS.

PLANE SOURCES OF SEISMIC WAVES

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The purpose is to make a detailed study of what happens when one has a source plane perpendicular to the free surface in a semi-infinite homogeneous isotropic elastic medium. Laplace transform methods due to Cagniard are used. The problem is an example in which the steady-state approach leads to quite trivial results—*i.e.*, a longitudinal input gives no secondary transverse wave, and the secondary longitudinal wave just cancels the input wave. When the source is taken into account there is a transverse secondary wave and a longitudinal secondary wave. Also a wave travelling with the Rayleigh velocity appears except when the source is a horizontal shear source. There is a sharp beginning for this latter phase only at the free surface. Below the free surface it merges smoothly

(analytically) with the other parts of the wave field. The problem may be generalized, and various diffraction problems handled, but when the source plane is not homogeneous or when the medium is not homogeneous, all simplicity vanishes from the problem.

PETROLOGY OF THE HOLDEN MINE AREA, WASHINGTON

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The Holden Mine, producing mainly copper and zinc, located in Chelan County, Washington, is in an area composed of igneous and metamorphic rocks. The igneous rocks include quartz diorite dikes and stocks, dacite dikes, and basic dikes. The metamorphic rocks include schists, gneisses, directionless granitic rocks, and partially metamorphosed igneous rocks. These rocks are part of the Paleozoic-Mesozoic eugeosyncline of sediments and volcanics forming the western part of the Cordilleran system. The metamorphism was predominately mesozonal but locally katazonal, and included both isochemical and metasomatic conditions of regional extent. The predominately isochemical metamorphism produced amphibolites, biotite schists, amphibolites interbedded with lime-silicate schists and marble, and lime-silicate granulites. The metasomatic metamorphism formed gneissic and directionless granitic rocks. Structurally the gneissic and schistose rocks form a northwesterly trending homoclinal sequence which, however, may contain tightly compressed isoclinal folds. High-angle faults offset the bands of schistose rocks.

Mineralization occurred during a late stage of the regional metamorphism and coincides with the zone of highest metamorphic grade in the area. The metallization, mainly pyrite, pyrrohotite, chalcopyrite, and sphalerite, was associated with the latest stage of metamorphic recrystallization and therefore took place under the same katazonal temperatures. The deformation accompanying the metamorphism was contemporaneous with and helped to provide channels for the metallization. Structural control for ore deposition is manifested by a minor cross fold at the eastern end of the ore body. The western end grades to assay limits.

ADDITIONS TO THE DEVONIAN AND CARBONIFEROUS FAUNAS OF NORTHEASTERN WASHINGTON

Betty Joyce Enbysk
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Several reports published within the past 10 years and the present study indicate that the Paleozoic strata of northeastern Washington, previously considered unfossiliferous, can no longer be thought barren ground for paleontologic study. Fossils representative of all the major animal groups and referable to every Paleozoic period except the Silurian have been found. The species have eastern North American or Rocky Mountain affinities. Three new collections are noted.

The first is from an isolated limestone exposure northwest of Metaline Falls, 1 mile south of the Canadian border. The faunule is probably Middle Devonian (Onondagan). Previously unreported species are: *Thurammina sp.*, *Aulacophyllum princeps*, *Hexagonaria* cf. *H. alternata*, *Coenites palmata*, and *Syringopora sp.* A reef environment is suggested. What is probably a new genus of Foraminifera related to *Endothyra* was secured.

An exposure of Weaver's Chewelah argillite near Kulzer in southeastern Stevens County contains an assemblage of Late Mississippian (Chester) age. The ostracods *Graphiodactylus tenuis*, *Jonesina craterigera*, and *Cavellina* aff. *C. coryelli* found here have been reported from a locality half a mile to the west. Previously unreported finds are: *Triplophyllum sp.*, *Spirifer* cf. *S. pellaensis*, *Chonetes sp.*, a conodont, and a trilobite.

The first record of Pennsylvanian in northeastern Washington is provided by *Spirifer* aff. *S. rockymontanus*, *Rhombopora nitidula*, and *Lophophyllidium* cf. *L. proliferum* from limestone near Springdale in southeast Stevens County. Six genera of Foraminifera have been recognized—*Rhabdammina*, *Ammobaculites*, *Endothyra*, *Millerella*, *Globivalvulina*, and *Trochammina*.

SANDY FACIES OF UPPER DEVONIAN STRATA IN SOUTHEASTERN ARIZONA

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Upper Devonian strata in the Pedregosa Mountains of southeastern Cochise County, Arizona, total 400 feet thick and are characterized by dolomitic quartz sandstones, platy siltstones and marls, and subordinate clastic limestones and silty dolomites. They contain considerably more sand and silt than correlative formations both to the east in New Mexico and to the west in Arizona. They overlie lower Ordovician (El Paso) limestone with local angular unconformity and grade into the overlying lower Mississippian (Escabrosa) limestone.

Paleontological evidence suggests that this Devonian sequence is to be correlated with the Martin limestone of southern Arizona and the Sly Gap formation of southern New Mexico and is older than the Percha shale of southwestern New Mexico. The fauna includes *Pachyphyllum nevadense* (Stumm), *Cladopora* sp. *Atrypa* spp., and *Cyathophyllum* sp., in common with the Martin fauna; and *Macgeea* sp., *Pseudodouvillina euglyphea* Stainbrook, and *Ptyctodus calceolus*, in common with the Sly Gap fauna.

Local abundance of colonial tetracorals and the predominantly clastic character of the sequence suggest deposition in shallow water, perhaps on a submarine bank but not close to any known shore. However, the unconformity between Devonian and Ordovician rocks may indicate the development of a local tectonic high in the region of the Pedregosa Mountains.

PROBLEMS IN GROUND-WATER GEOCHEMISTRY NEAR OGDEN, UTAH

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More than 300 water samples from wells and springs near Ogden, Utah, have been chemically analyzed as a phase of a joint ground-water study by the U. S. Geological Survey and the Bureau of Reclamation. From these data a map has been prepared to show areas where each of three chemical types of water predominates—namely, calcium magnesium bicarbonate, sodium bicarbonate, and sodium chloride types. The sodium bicarbonate water is interpreted as the end product of base exchange, probably in sediments containing sodium-rich clays, involving water that began as the calcium magnesium bicarbonate type. The sodium chloride waters apparently originate in fracture zones related to the Wasatch fault.

Sodium chloride water predominates in an area of about 50 square miles north-northwest of Ogden. Isochlor maps show "hot spots"—mounds of exceptional chloride-ion concentration thought to reflect the presence of "subsurface springs" discharging from fractures in the older rocks into the valley fill that forms the principal aquifers. Adjacent to that chloride-water area, zones of mixed waters are recognized. At the west extremity of the area of study, a saline-water area is related to a presumed fault block that finds surface expression in the rocks of Precambrian age forming Little Mountain. Geophysical data indicate that the valley fill, largely lake beds, is at least 5000 feet thick in adjacent areas between Little Mountain and the Wasatch Mountains.

The conditions that control the occurrence, observed in a few places, of aquifers carrying fresh water sandwiched between aquifers carrying saline water remain unknown.

BATHYMETRY AND POSTGLACIAL SEDIMENTS OF LAKE WASHINGTON

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Lake Washington near Seattle occupies a deep, narrow trough excavated by the Puget Ice Lobe during the Pleistocene. Extending along the center of the trough is a broad ridge that stands 5–30 feet above narrow valleys on either side. Thus the trough in cross section is W-shaped rather than U-shaped as are most glacial troughs.

Cores of the sediments in the trough show blue clay 2–36 feet thick overlain by olive-gray limnic peat 5–55 feet thick. The blue clay consists of rock flour of meltwater origin, and the limnic peat consists of planktonic organisms that began to accumulate following the meltwater stage.

Within the limnic peat are a layer of volcanic ash about 2 inches thick and two layers of varved peat, each about 3 inches thick, which occur on opposite sides of the ash layer. Radiocarbon analyses of peat in near-by bogs place the age of the ash layer at 6800 years and the age of the blue clay-peat contact at about 12,000 years. The estimated ages of the lower and upper varved layers are 11,000 and 4500 years, respectively.

Core profiles across the lake show that the trough was U-shaped at the close of the blue-clay deposition, and that the W-shaped profile was well developed at the time of the ash fall. The W-shaped cross section results, evidently, from a lower rate of sedimentation at the margins of the trough than at the center owing to strong convection currents at the trough margins.

FOSSIL GREEN ALGAE FROM THE MIOCENE OF THE COLUMBIA PLATEAU

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Volcanic ash sediments from above the Columbia River basalt in Oregon, long famous for plant and animal remains, have revealed upon microscopic examination a varied and in general well-preserved pollen flora, in addition to other plant microfossils. Among the latter three members of the Chlorophyta (green algae) from the Mascall and Stinking Water formations, of Middle Miocene age, have been identified. These belong to the genera *Botryococcus*, *Pediastrum*, and *Tetraedron*. *Botryococcus* in a form apparently not greatly different morphologically from the extant species, *B. braunii* Kuetzing, has been recorded from the Ordovician onward; this is the second record of its Tertiary occurrence in North America. At least two species of *Pediastrum*, one morphologically inseparable from the common *P. boryanum* (Turp.) Meneghini, the other described as a new species, are recorded as a first appearance from American Tertiary strata. A single well-preserved specimen of *Tetraedron* appears to represent the only fossil record of this genus beside a specimen very different morphologically, described from the Green River shale.

STRUCTURAL GEOLOGY OF THE NORTHEASTERN PART OF THE SODA MOUNTAINS, BAKER, CALIFORNIA

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The Soda Mountains consist of Precambrian paragneiss, Early Cambrian (?) dolomite and quartzite (3000+ feet), Middle Paleozoic (?) dolomite (2000+ feet), Late Paleozoic limestone and hornfelsed shale (11,500+ feet), Early Triassic limestone and argillite (1700+ feet), Triassic-Jurassic andesite and sandstone (7000+ feet), Late Mesozoic intermediate and acidic plutonics, and Early Pliocene fanglomerate, monolithologic limestone breccia, and tuff (5300+ feet).

Late Mesozoic deformation produced three areally separate low-angle thrust complexes. Inconclusive evidence suggests the thrusting was westward. The largest complex involves highly disordered allochthonous Late Paleozoic limestone blocks that have been relatively down-faulted into equally disordered autochthonous Mesozoic volcanics. Granitic invasion followed block faulting and was locally guided by pre-established vertical and low-angle faults.

The dominant structure in the Soda Mountains is a N.25°W. right lateral fault zone, herein called the Soda-Avawatz fault, which divides the region into areas of distinctly different formations. The zone ranges in width from 1 to 2 miles and includes three principal faults, numerous subsidiary faults, and a large squeezed-up "anticline". Major movement occurred in Late Cenozoic time, but proximity of parallel granite dikes suggests the lineament may date from the Late Mesozoic. Strongest evidence for right lateral displacement is the en echelon pattern of faults and folds. Horizontal displacement is probably more than 3 miles. The Soda-Avawatz fault continues northward along the

east side of the Avawatz Mountains and joins the Death Valley strike-slip fault system; together they form a regionally significant right lateral fault zone.

ENERGY OF EARTHQUAKES

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In a paper presented at this meeting, Gutenberg and Richter have revised equations that permit the calculation of earthquake energy E. Using these equations, the writer finds that in the average year 1904 to 1954, $\log E = 25.0$; the energy released in earthquakes is less than 1 per cent of that released in the earth by radioactive processes. At all focal depths h, the frequency of earthquakes releasing a given energy E decreases nearly exponentially with increasing E. The average annual number of shallow shocks ($h = \leq 60$ km) in a range of ¼ unit of $\log E$ increases from 0.04 for the largest known ($\log E = 25.2\pm$) to several hundred thousand producing motion near the epicenter barely above the usual unrest of the ground ($\log E = 10.0\pm$). About two-thirds of all energy is released in the crust above 35 km, only 3 to 4 per cent below 300 km. Shocks originating deeper than 300 km are known in the relatively narrow circum-Pacific and Alpide belts only; there the energy release has a minimum at depths near 300 km and secondary maxima near 350 to 400 and 550 to 650 km. With increasing h, the maximum energy E^* found for a single shock decreases:

h	20	150	350	650	720 km
$\log E^*$	25.2	25.0	24.5	23.8	22.6

No shocks are known below 720 km; this could be caused by decrease of the apparent viscosity coefficient from 10^{22} to 10^{23} poises in the crustal layers to about 10^{20} poises below 700 km.

MAGNITUDE AND ENERGY OF EARTHQUAKES

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Heretofore three imperfectly consistent magnitude scales had been in use: M_L determined from records of local earthquakes in California according to the original definition by Richter; M_S from the amplitudes of surface waves for shallow teleseisms; M_B found from the amplitude/period ratio of body waves for shallow and deep-focus teleseisms, including a correction for large shocks. It is now believed that the uncorrected magnitude m_B found from body waves offers the best basis for further research, and that approximately

$$m_B = M_S - 0.37\,(M_S - 6.76) \tag{1}$$

Values of m_B calculated directly from body-wave data by use of revised tables or graphs, and from surface-wave amplitudes using equation (1) or a corresponding nomogram by Mr. Nordquist, are adjusted to a weighted mean, when both are available; this is termed the "unified magnitude" and denoted by m. The relationship between M_L and m is roughly

$$m = 1.7 + 0.8\,M_L - 0.01\,M_L^2 \tag{2}$$

Tentatively, the energy E is found from

$$\log E = 5.8 + 2.4\,m = 11.8 + 1.5\,M_S \tag{3}$$

which, under favorable conditions, gives $\log E$ probably within one unit.

GEOLOGY OF THE CORRAL CANYON AREA—STILLWATER RANGE, CHURCHILL COUNTY, NEVADA

David Hand
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The Stillwater Range, in the Corral Canyon area, consists of folded and faulted sediments and volcanics of Pennsylvanian (?) to Triassic age which have been intruded by Jurassic (?) diorites. Faulting was responsible for the uplift of the range and controls many of the topographic features.

Limestone, the only sedimentary rock in the area, was thoroughly silicified, probably during one of the stages of the dioritic intrusion. Zones of weakness developed in the early-formed diorite, and these zones controlled the emplacement of an aplitic differentiate during the last stages of intrusive activity.

Significant amounts of titanium mineralization occur in the dikes where the titanium is present in the form of anatase. Specimens of the dike rock show that the anatase is the alteration product of earlier sphene, which was the original titanium mineral in the dikes. The diorite contains ilmenite and rutile, which indicates that the original dioritic magma was rich in titanium.

Continued crystallization of the magma caused deuteric alteration in both the titaniferous dikes and the diorite. The sphene in the dikes was altered to an aggregate of anatase, quartz, and calcite; the feldspar in the diorite was altered to scapolite and clay minerals.

Petrographic analyses suggest that the diorite of the Corral Canyon area is genetically related to the diorite in the Cottonwood Canyon area and to the diorite in the Buena Vista iron deposits.

ANORTHOSITE IN BOEHLS BUTTE QUADRANGLE, IDAHO

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Three bodies of anorthosite 10–20 km long and several smaller ones occur in the lower part of the Prichard formation of the Precambrian Belt series northwest of the Idaho batholith. Some of the rock is massive, but some has a beddinglike structure caused by alternation of coarse pure plagioclase layers with thinner biotite- or hornblende-bearing layers. Contacts are gradational; plagioclase replaces quartz in the surrounding schist and quartzite. Kyanite, andalusite, sillimanite, muscovite, biotite, and sheetlike inclusions of schist are common in the anorthosite; the kyanite occurs locally with hornblende. An inhomogeneous texture is typical: bytownite (An_{88}) occurs as small grains between large round grains of andesine (An_{43}) and as lamellaelike inclusions in the andesine. The andesine-bytownite ratio is highly variable. That the emplacement was a chemical rather than a mechanical process is suggested by gradational contacts, orientation of inclusions and planar structure, mineralogy, and texture. The occurrence of sillimanite with muscovite suggests that temperature during the crystallization was below 650°C. Biotite- and quartz-bearing garnet amphibolite that occurs in small sill-like bodies in the surrounding schist and occasionally in the anorthosite is a complementary mafic rock. It was probably derived along with the anorthosite by metasomatic differentiation of femic and salic constituents of gabbroic or dioritic material.

ROCK-BORING ISOPOD

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On the south shore of San Pablo Bay, California, San Pablo sandstone (Neroly) and Pinole tuff exposures in the intertidal terrace are riddled with borings by a marine isopod, *Sphaeroma pentadon* Richardson. This paper calls wider attention to A. L. Barrows' detailed report (University of California Publications in Zoology, 1919) of this occurrence. By weakening the rock and thus facilitating its removal by feeble wave attack, the isopods here play a major, if not the chief, role in erosion of the terrace and thereby join that group of intertidal organisms whose contributions to coastal erosion are becoming increasingly appreciated.

WIND ABRASION BY PARTICLES IN SUSPENSION

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Occurrence of anchored ventifacts with faces oblique to inferred average erosive wind direction, with leeward faces inclined more than 16°, and with sharp crestal edges between windward and leeward faces suggests that abrasion was produced chiefly by a stream of suspended or partly suspended particles following local deflections of the wind stream, rather than by impact of undeviating, saltating sand grains. That suspended material might be capable of producing ventifact shapes is suggested by previous studies on wind flow over obstacles.

Consideration of wind-flow deflection suggests that saltating sand grains do not follow straight, inclined downward paths near obstacles, but are more or less deflected with the wind stream over or around the obstacles. Paths of finer particles are deflected more than those of coarser particles and have a correspondingly lower angle of impact on the obstacle surface. Thus source and size distribution of wind-transported abrasive material, more than character of ventifacts, may determine whether abrasion will result largely from low-angle scour by suspended material or from high-angle impact by saltating grains.

STRUCTURAL TRENDS IN OREGON

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A recently compiled geologic map of the State of Oregon shows major structural trends in somewhat greater detail than previously done on a state-wide scale. Three major Cenozoic uplifts which dominate the tectonic pattern in Oregon are: the Coast Range anticlinorium, the Cascade uplift, and the Klamath-Blue Mountains uplift. The last-named trends N. 60° E. across the State somewhat following a pattern established during the Mesozoic. Mesozoic rocks of the Klamath Mountains trend N. 10° E. near the coast and shift to N. 35° E. in the Cascade foothills. In the Blue Mountains schistosity of Carboniferous sediments and trends of pre-Cenozoic dikes parallel the N. 60° E. trend of the uplift. Baker Valley and La Grande Valley grabens and the Wallowa horst trend N. 30° W., athwart and normal to the Blue Mountains uplift.

South of the Blue Mountains in eastern Oregon aerial photographs reveal a remarkable fault and joint pattern in Pliocene lavas. Three large upfaulted blocks—Abert Rim, Hart Mountain, and the Steens Mountains—trend N. 20° E.; Summer Lake-Chewaucan Marsh graben trends N. 26° W.; and Upper Klamath Lake graben trends N. 5° W. Swarms of lesser faults exhibit various patterns, for the most part trending northwesterly, and so situated as to compensate for movements of the larger blocks. The Coast Range and Cascade uplifts trend N. 5° E. and transect the diagonal trends mentioned above. Most of the Quaternary vulcanism centers at the intersection of the Cascade and Blue Mountain uplifts. Certain features suggest that the Cascade Range is a tilted fault block.

NATURE OF THE FAULTING IN LARGE EARTHQUAKES

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The Dominion Observatory has applied Byerly's method to determine the direction of faulting in 65 earthquakes; this brings to 75 the total number of earthquakes so analyzed. Of these, 7 have received confirmation by comparison with observed faulting.

The method is ambiguous in that two planes are defined for each solution, with no indication of which is the fault. This does not obscure the fact that of the 75 earthquakes all but 8 resulted from strike-slip faulting. Of these 8, 5 came from the Pacific coast of North America, 2 from the Hindu Kush, and 1 was an anomalously deep-focus earthquake off the coast of Spain. Otherwise, for all circum-Pacific areas and for the Mediterranean, and for focal depths ranging from 12 kms to 650 kms, strike-slip faulting appears to be the rule. Within any particular area the strike direction of

the faults is random. The dip directions may have some consistent orientation, although this is not clear.

In any solution the intersection of the two planes defines a unique line, here called the *null vector*. For any area the null vectors tend to lie parallel to a vertical plane having the direction of the associated geographical feature. The correlation is too definite to be accidental and must be regarded as a confirmation of the method. The physical significance of the null vector is not understood.

ENGINEERING GEOLOGY OF THE SACRAMENTO RIVER, CALIFORNIA

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The Sacramento River is constantly adjusting its channel shape, grade, and alignment to accommodate a set of man-made conditions which began a century ago. These conditions include encroachments upon the flood plain of the river which have continued at an accelerated rate down to the present with reclamation and utilization of the flood plain for agricultural, residential, and industrial purposes and the construction of railway and highway bridges and embankments. They include interference with the natural flow by means of channelization for navigation, regulation of the flows into bypasses, the construction of levees to contain the flood waters, and the construction of dams and reservoirs for flood control and conservation storage and the impounding of mining debris.

These conditions are believed to have stimulated the tendency of the Sacramento River to readjust its channel shape, grade, and alignment. The problems of engineering geology associated with the encroachments and the efforts to control both the flows of the stream and the readjustments include: investigation of the bank and channel materials, the transportation of debris, the tendency to scour and fill, foundations for engineering structures, the locations for dam and reservoir sites, seepage beneath levees and weirs, and the location, quality, and quantity of construction materials.

RESURGENT BOILING AND THE FORMATION OF MAGMATIC PEGMATITES

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Some features of magmatic pegmatite bodies, especially those with recognizable internal zoning, are difficult to explain solely in terms of progressive crystallization of liquid, whether or not reaction between crystals and rest liquid is inferred. These features, each common enough to require consideration in any theory of pegmatite genesis, include (1) marked asymmetry of zonal structure, (2) certain types of widespread mineral replacements, generally showing a definite sequence of development, (3) temporal overlap in formation of zones and replacement bodies, (4) discrepancies between the composition of many interior zones and the composition that would be expected if they had formed within an essentially closed system whose liquid phase was yielding solid material only, and (5) evidence for vigorous corrosion and replacement of quartz, potash feldspar, and other minerals simultaneously with crystallization of the same minerals at other points within the same pegmatite bodies.

It is suggested that these features can be accounted for in terms of resurgent boiling of crystallizing pegmatitic rest liquid, accompanied by condensation of the vapor elsewhere within the partly consolidated pegmatite body. This would change the composition of the rest liquid in progressive fashion by selective removal of constituents from regions of boiling and by addition of constituents in regions of condensation. The effects of vapor transfer might well reflect some degree of gravitative control. In contact with already-crystallized material, the condensate itself would be a powerful corrosive agent and could contribute to extensive mineral replacement. Its composition and the nature of its solid products would change progressively as long as boiling continued.

LOWER MISSISSIPPIAN STRATIGRAPHIC UNITS IN SOUTHERN NEVADA

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The Dawn, Anchor, Bullion, Arrowhead, and Yellowpine members of the Monte Cristo formation are readily recognized over much of southern Nevada and adjacent California and are recommended for use in mapping and correlation. Approximate thicknesses in feet at representative sections in Clark County, Nevada follow:

	Spring Mountains Mountain Spring Pass Sec. 19 T. 22 S., R. 85 E.	Muddy Mountains White Basin Fault Scarp Secs. 30-31 T. 18 S., R. 67 E.	Mormon Mountains Road to Carp Sec. 31 (?) T. 11 S., R. 69 E.
Yellowpine	125	170	305
Arrowhead	20	15	15
Bullion	385	425	380
Anchor	220	250	135
Dawn	80	180	50

The Dawn member, relatively chert-free, dark-gray to black limestone, rests in sharp contact on Devonian rocks. Alternating dark-gray to black, thin, nodular beds of flint and limestone characterize the Anchor member which has gradational contacts above and below. The Bullion member is chiefly massive, cliff-forming, coarse, light-gray-weathering limestone but is extensively dolomitized in the Goodsprings district. Outcrops of the Arrowhead member, thin-bedded, nodular, sublithographic, black limestone with clay partings, are covered by talus in many places. Basal and upper contacts are sharp, and this distinctive, thin member is of great potential value as a key bed in mapping and correlation. The Yellowpine member, coarse, dark-gray to black, medium- to thick-bedded limestone, is succeeded by basal sandstone in the Bird Springs or Callville formation.

TWO NEW GENERA OF CARBONIFEROUS TAXODONT PELECYPODS

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A new genus is proposed for those Carboniferous nuculanid species having chevron-shaped anterior teeth, a continuous hinge plate, and rectangular and chevron-shaped posterior teeth. An oblique internal buttress is usually present below the umbo. It differs from *Polidevcia* Chernshev 1951 in possessing a well-defined chondrophore.

A new genus is also proposed for those Carboniferous yoldiid species having a strongly opisthocline chondrophore, a continuous hinge plate, and crowded, chevron-shaped and rectangular teeth.

LINEAR DISSIPATION IN ROCKS

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A general linear analysis is used to correlate the inelastic behavior of rocks under static and dynamic stresses of small amplitude. Three outstanding strain properties of rocks are shown to be related: (1) the logarithmic form of the transient creep curve; (2) the near constancy of internal friction with frequency; (3) the near absence of velocity dispersion in body waves.

The experimental form of the creep function is discussed and compared with theoretical derivations based upon a mechanism of dislocations at low stress levels. The proposed creep function for rocks is as follows:

$$\varphi(t) = q \ln (1 + at)$$

where $\varphi(t)$ is defined in accordance with Boltzmann's theory. The order of magnitude of a is apparently smaller than predicted from dislocation theory. Values of the creep constant q are given from torsional creep tests of igneous rocks at low stresses and surface conditions of temperature and pressure.

HURRICANE FAULT

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A new interpretation of the Hurricane fault structure is offered. The La Verkin thrust fault is described; its importance in the genesis of the accepted interpretation of the Hurricane fault structure is explained. The new interpretation of the Hurricane fault is further supported by descriptions of similar faults in the region—the Gunlock, Cedar Pocket Canyon, and Toroweap Valley faults.

The new interpretation of the Hurricane fault is that the fault is not a normal fault but a compressional fault showing a probable reverse displacement with considerable strike slip. Descriptions of the Hurricane, Toroweap Valley, Gunlock, and Cedar Pocket Canyon faults are included. Evidence for the interpretation is given, and a general review of the structure and its genesis in the St. George basin region is given.

STRUCTURE AND DOLOMITIZATION IN CRYSTALLINE MAGNESITE DEPOSITS, PARADISE RANGE, NYE COUNTY, NEVADA

Conrad Martin

Crystalline magnesite deposits on the west flank of the Paradise Range in northwestern Nye County, Nevada, are found over an area 4 miles long and 2 miles wide. They occur in the imbricated upper plate of a major thrust, within a dolomite member in Upper Triassic limestone and shale. These have been folded, faulted, regionally metamorphosed, and intruded by sill-like masses of granodiorite and a variety of dikes.

Toward the end of the Triassic, the sediments were intruded by andesite dikes accompanied, perhaps, by normal faulting. These dikes also traverse the magnesite and are involved with it in the folding and thrusting which has been dated as early Jurassic. Following the thrusts came the intrusion of granophyre dikes. Late in the Jurassic, or possibly early in the Cretaceous, the granodiorite masses and related dikes were emplaced. Minor faulting may also have taken place at this time. In Tertiary time the rhyolite dikes were intruded, and the normal faulting, which continues into the present, was extensive.

The magnesite is invariably dolomitized along flexures, faults, and shear zones. The breccia along the older faults has been completely recrystallized. Pendants of magnesite within the granodiorite have been largely converted to brucite.

The magnesite is believed to be older than the early andesite dikes, and certainly older than the early Jurassic thrusts. This would make it about Late Triassic.

In the light of this evidence, the previously suggested genetic relationship between the magnesite and intrusives is no longer tenable. This invites restudy of the magnesite deposits and the problem of their origin.

MINERAGRAPHIC TECHNIQUE FOR THE STUDY OF FERROMAGNETIC MINERALS AS APPLIED TO PYRRHOTITE

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Ferromagnetism is a vectorial property related to structure. Studies by physicists of suitable metals have shown that ferromagnetism is due to the existence of small regions or domains, each magnetized to saturation by internal processes. The domains usually are so arranged that the polarity due to each domain is compensated by that of surrounding domains. Therefore no resultant external magnetic field exists. The boundaries of a domain are regions of magnetic vector direction change, and thus are regions of inhomogeneity of magnetic field. Such boundaries occurring on or near a metal surface will attract small ferromagnetic particles placed on the surface, with a resulting depiction of the domain arrangements at the surface. Configurations thus shown are called Bitter figures, after their discoverer. A colloidal suspension of magnetite is effective in producing the figures.

Polishing of metal surfaces commonly results in the creation of an amorphous (Beilby) layer. Studies by physicists during the past 20 years have shown that removal of this layer by the electrolytic method of polishing is necessary for obtaining true Bitter figures.

The author has attempted to apply the Bitter technique to polished surfaces of ferromagnetic minerals. Apparently true Bitter figures have been produced on polished pyrrhotite prism surfaces. The domains are lamellar, about 20 microns thick, and parallel to the basal pinacoid. Their arrangement and saturation intensity are in good agreement with the literature values furnished by other types of measurement. Attempts to electropolish pyrrhotite met with success, and patterns coinciding with those above were produced on the electropolished surfaces.

MICROFOSSILS FROM MESOZOIC PHYLLITES IN WHATCOM COUNTY, NORTHWESTERN CASCADES, WASHINGTON

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During Misch's study of the northern Cascades, thick Upper Jurassic-Lower Cretaceous siltstones and graywackes were found in the Nooksack North Fork area. Megafossils collected have been determined by J. A. Jeletzky as Oxfordian-Kimmeridgian, Portlandian, and Valanginian in age. The fossiliferous sediments grade eastward into slaty to phyllitic rocks. Some of the thin sections of these rocks revealed well-preserved silicified micro-organisms, including Foraminifera, Radiolaria, and unidentified objects of probable organic origin. The Foraminifera include uniserial types probably referable to the family Lagenidae and certain others which suggest an age no older than Jurassic. The containing rocks are very fine-grained chlorite-sericite phyllites. Clastic grains and graded bedding are still visible. Penetrative deformation, indicated by cleavage and mineral orientation, is pronounced, except in a fine-grained graywacke that is less recrystallized.

ENGINEERING STUDY OF THE EUREKA, CALIFORNIA, EARTHQUAKE OF DECEMBER 21, 1954

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The observed damage, at most, classes this shock as a moderate earthquake, which caused over-all slight structural damage to some nonearthquake-resistive structures and none to earthquake-resistive structures.

Previously earthquake-damaged structures, notably the Humboldt County Courthouse, again were damaged.

Damage to structures and underground pipe lines was found in the poor-ground areas. Previous settlements, as well as subsidence at the time of the shock, were noted at some of the damaged areas.

Fluid motion in tanks located about 200 miles from the epicenter was similar to that noted in other shocks.

EARTHQUAKE EPICENTERS IN THE STATE OF WASHINGTON

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The paper summarizes results obtained in locating epicenters from seismographic and other data including instrumental data from Seattle and the British Columbia network of stations. New information is obtained on seismic-wave velocities in the Puget Sound area and on certain characteristics of local crustal structure. The relationship between epicenters and local faults is discussed.

RAYLEIGH WAVES INCIDENT UPON A CORNER

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Laboratory studies indicate that when a Rayleigh wave is incident upon a right-angled corner and measurements are made some distance from the corner, approximately 15 per cent of the incident energy is reflected as a Rayleigh wave, 30 per cent is transmitted around the corner as a Rayleigh wave, and the remainder is radiated from the corner as compressional or shear waves. The phase of the reflected Rayleigh wave is unchanged, that of the transmitted Rayleigh wave shifted through 180° measured with respect to the normal.

Field studies near a large cliff on the Greenland icecap clearly indicate the existence of both reflected and transmitted Rayleigh waves. Although meager data are available, phase relations appear to agree well with the model results.

MICROSEISMS IN THE ELEVEN- TO EIGHTEEN-SECOND PERIOD RANGE

Jack Oliver and Maurice Ewing
Lamont Geological Observatory, Palisades, N. Y.

Microseisms in the 11- to 18-second period range have been recorded on the Columbia long-period seismographs at the Palisades and Bermuda stations. A study of such waves recorded during the hurricane seasons of 1954 and 1955 shows a clear correlation between the arrival of the microseisms and the arrival of hurricane-generated ocean swell of identical periods at near-by coasts. One unique storm, hurricane Dolly of 1954, passed the Palisades station with a velocity greater than the group velocity of gravity waves in water, thus providing a simple dispersion pattern in both swell and microseisms to strengthen the correlation. Results are strongly in favor of an ocean-wave coastal-effect theory of microseism generation for waves in this period range.

TECHNIQUES FOR RECORDING AND PRESENTING DAM-SITE EXPLORATION DATA

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A recent exploration program to determine the foundation conditions at a dam site in California stimulated some innovations in the standard techniques of recording and presenting data. Some changes were made in standard methods of the graphic presentation on detailed geologic logs of exploration tunnels and core holes. The graphic presentations were changed to make logs easier to read and to make some of the essential data more apparent. Photographs of the core with a graphic legend were taken to supplement the core log. Isometric drawings of tunnel sections, which were driven along shear zones, were found useful in depicting the peculiarities of shear planes which could not be shown on the more conventional type of presentations. Isometric block diagrams of the abutments and of the spillway area were found useful in presenting a picture of the entire scope of exploration in relation to detailed cross sections in two directions on the same drawing.

In the expanding field of engineering geology there is a constant need for better techniques. Engineers involved with understanding and applying the geology of a project are anxious for any tech-

niques in presentation which are simplified without sacrificing accuracy. It is hoped that the techniques presented here will be of help to others involved with dam-site exploration and that there will be a more frequent exchange of ideas for techniques involved in presenting data for engineering-geology studies.

RADIOCARBON, MAMMOTHS, AND MAN ON SANTA ROSA ISLAND

Phil C. Orr

The Santa Barbara Channel Islands are an insular extension of the Santa Monica Mountains, connected to the mainland in pre-mid-Pleistocene times. On Santa Rosa Island, two species of extinct dwarf mammoth, radiocarbon dated at 29,650 years by Lamont Geological Observatory, occur in the truncated Wisconsin alluvial fans and deltas and in deposits on the higher terraces believed to the Illinoian in age.

Assuming a eustatic minus sea level of 300 feet, submarine topography indicates about 6 miles of coastal erosion, resulting in 50-foot sea cliffs, where fire-reddened earth, burned mammoth bones, and charcoal are most easily explained as the work of man. Abalone shells in the top 12 feet of alluvium, radiocarbon dated at 6800 years, were definitely discarded by human beings. Stratigraphic studies indicate the possibility that the mammoth existed until near this time.

Although there is a 25-foot wave-cut terrace of Third Interglacial age, and set-back sea cliffs which indicate a postglacial 5-foot sea stand, no evidence for a mid-Pleistocene orogeny, claimed for the southern coastal region, has been recognized. If such an uplift occurred on the Channel Islands, we must account for a 400-foot drop in the Santa Barbara Channel and for the pisolites, which soils presumably were created under Pliocene conditions and occur on the higher terraces of Santa Rosa and in the San Diego region.

COMPOSITION OF ORGANIC MATTER IN MARINE SEDIMENTS: PRELIMINARY DATA ON HYDROCARBON DISTRIBUTION IN BASINS OFF SOUTHERN CALIFORNIA

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As part of a program to evaluate the influence of the depositional environment on the composition of organic matter in marine sediments and the changes in composition which occur in the upper zones of sediment, cores from several basins representing different sedimentary environments off southern California have been examined for extractable organic matter, hydrocarbon content, and certain other properties. The data are of particular interest in considerations of the early stages of petroleum formation.

Chromatographic separations of hydrocarbon fractions were made which are comparable with Smith's work on the Gulf of Mexico and the Santa Cruz Basin off southern California. This technique permitted semiquantitative separation of a pure paraffin naphthene hydrocarbon fraction, an impure aromatic fraction, and an asphaltic fraction from the more complex bulk of the organic materials.

Hydrocarbons constitute 2.3 to 18.6 per cent of the extractable organic matter, 0.05 to 0.64 per cent of the total organic matter, and 0.003 to 0.038 per cent of the total dry sediment in the three basins examined. The hydrocarbon content differs slightly in the different basins, but variations with depth (to 4 meters) appear to be random on the basis of the few samples studied. The average potential petroleum yield, computed from hydrocarbons extracted from the sediments, is about 10 times the eventual recovery from oil fields of the Los Angeles Basin.

STRUCTURE OF CHAMOSITIC IRON ORE DEPOSITS NEAR TAJMIŠTE, WESTERN MACEDONIA, YUGOSLAVIA

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The Tajmište district contains the largest amount of iron ore discovered to date in Western Macedonia. The ore comprises three or more sedimentary beds largely composed of iron silicates, including chamosite. The ore beds, Devonian (?) in age, are separated from one another by black phyllite. Similar phyllite constitutes several overlying members which alternate with thick Devonian limestones. Triassic dolomite and limestone rest unconformably upon these rocks.

Although the Tajmište district is virtually in the shadow of Dinaric structures, ordinary thrusts and pronounced folds are rare. The region is a mosaic of irregular, slightly tilted fault blocks. Many of the blocks are limestone, where now exposed, and most are bounded by normal faults with inconstant trends and unusually sharp curvature. The block faulting is earlier than the present topography, which is only indirectly influenced by the displacements. Despite the apparent scarcity of sharp folds and distinct thrusts, near-horizontal movement prior to the block faulting is suggested by low-angle shearing phenomena widely distributed throughout the phyllite members. The phyllitic foliation itself is tentatively ascribed to penetrative shearing. Minute wrinkles, and wisps of mylonitic material are commonplace. The implied differential movements within the phyllite may explain marked discrepancies in the thickness of enclosed ore and in the number of ore beds found in closely spaced drill holes. The ore itself and most of the limestone units in the district show comparatively little differential movement; they resisted the deformation of the rock mass as a whole.

GEOLOGIC MAP OF CLARK COUNTY, NEVADA

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Since 1952 the U. S. Geological Survey, in co-operation with the Nevada State Bureau of Mines, has been engaged in the study of the geology and mineral resources of Clark County, Nevada. One of the products of this investigation is a geologic map, one in a series of county geologic maps, showing the geologic setting of the mineral deposits. It will assist in evaluating the mineral resources of the county and will also be used in planning future detailed geologic work. Approximately 70 per cent of the map was compiled from previous work; the remainder was mapped by Geological Survey personnel during the present study.

In eastern Clark County Precambrian rocks have been divided into two major groups, igneous and metamorphic; in southern Clark County the Precambrian rocks have not been divided. Sedimentary rocks of lower and middle Paleozoic age, which thicken westward from the margin of the Colorado Plateau toward the axis of the Cordilleran geosyncline, have been separated generally into systemic units and locally into formational units. Rocks of late Paleozoic, Triassic, and Jurassic age are widespread throughout the county. Continental Cretaceous deposits, which once covered much of the region, are now found only in the eastern half of the county. Tertiary igneous rocks underlie broad areas in southern Clark County; Tertiary continental deposits are common in eastern Clark County. Quaternary deposits cover large areas of the valley floors.

DETERMINATION OF CRUSTAL STRUCTURE FROM PHASE VELOCITY OF RAYLEIGH WAVES. PART 1: SOUTHERN CALIFORNIA

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A method of deducing local changes in crustal structure from variations of phase velocity of Rayleigh waves is described. The method utilizes the prolonged, sinusoidal trains of dispersed Rayleigh waves characteristic of long oceanic propagation paths. Crests and troughs of these waves may be

followed across a triangular array of sismograph stations when the station separations are not more than a few wave lengths. Phase velocity and direction of approach may be determined for waves of a given period. By comparing observed phase velocity with an experimentally determined phase-velocity curve representative of the average continental crust, local crustal thickness is obtained.

Application of the method to Southern California leads to the following results: (1) normal crustal thickness in the Peninsular Range Province; (2) increase of mean crustal thickness by about 50 per cent in the Sierra Nevada block; (3) significant decrease in crustal thickness, possibly as much as 50 per cent in the continental borderland. The significance of these results is discussed.

Lg WAVES IN CALIFORNIA

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It is important for tectonic theory to determine the elastic parameters of crustal layers in orogenic belts. The *Lg* earthquake phase provides a convenient method for measuring shear velocity in the upper part of the silicic crust. *Lg* velocity determinations have been made for the Sierra Nevada block, the Coast Ranges, and the San Joaquin Valley of California. The results give the same value for shear velocity in these structural belts as that obtained for transcontinental paths.

The result further supports the interpretation of phase-velocity variations of Rayleigh waves as indicative of changes in crustal thickness.

GEOLOGY AND IRON-ORE DEPOSITS OF THE NORTHERN PART OF THE CORTEZ MOUNTAINS, EUREKA COUNTY, NEVADA

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The northern part of the Cortez Mountains, extending 20 miles south from Palisade, Nevada, is composed of a thick sequence of flow and pyroclastic rocks of Tertiary age. These include at least 2500 feet of an older sequence of Eocene or Oligocene age and at least 1000 feet of a younger sequence of late Pliocene and early Miocene age that unconformably overlies the older rocks.

Rocks of the older sequence range from andesite to latite. They are folded into north-trending open folds and are cut and metamorphosed by intrusive rocks of Oligocene (?) age ranging from diorite to granodiorite. The older volcanic rocks are extensively altered, with enrichment in K and Fe.

The younger sequence of rocks ranges from andesite to rhyolite. They dip from a few degrees to 40°E. and interfinger with the Humboldt formation along the eastern edge of the range.

Bodies of hematite and magnetite at the Barth and Modarelli iron mines and several prospects are replacement deposits formed along shear zones and at the intersections of major faults in the older series of volcanic rocks. The deposits are genetically related to the Oligocene (?) intrusive rocks.

NICKELIFEROUS LATERITE IN NORTHWESTERN CALIFORNIA

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Nickeliferous laterite occurs on old erosion surfaces underlain by serpentine and peridotite in northwestern California. Deposits studied to date, principally in the Gasquet and Ship Mountain quadrangles in Del Norte County, lie on relatively flat-topped mountains and on high benches,

shoulders, and saddles on these mountains. The mountain crests are remnants of Diller's Klamath peneplain, which is pre-Late Miocene in age. A slightly lower erosion level, represented by high benches and saddles, is overlapped on the west by the Upper Miocene Wymer formation. Vertical uplift of the region since Wymer time has been 1500 to 2000 feet.

These deposits are similar to nickeliferous laterites elsewhere. They are residual accumulations derived by intense chemical weathering of serpentine and peridotite. For economic considerations the laterite may be divided into an upper iron oxide zone, an intermediate silica zone, and a basal weathered bedrock zone.

The iron oxide zone is red-brown, pisolitic hematite at the surface, grading downward into punky, ochre-colored limonite. In the lower portion of this zone and penetrating the partially decomposed bedrock there is, in places, a zone characterized by the presence of silica boxwork. The boxwork is derived by deposition of silica carried by descending solutions along joints in the bedrock. The weathered bedrock zone consists of partially decomposed serpentine and peridotite and grades downward into fresh bedrock. All three zones are enriched with nickel.

Depth of the laterite is highly variable from place to place, depending largely upon permeability of the rock, which in turn depends upon spacing of joints and other fractures.

DESERT HOT SPRINGS EARTHQUAKE OF DECEMBER 4, 1948, AND ITS AFTERSHOCKS

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The Desert Hot Springs earthquake of December 4, 1948, was one of the larger recorded earthquakes of Southern California. Because of its desert location, damage was minor. The assigned epicenter is 33° 56.4′ N., 116° 23.1′ W.; origin time, 23:43:16.7 G.C.T.; magnitude, 6½. The ground surface was not broken, except by landslides.

The main shock was followed by numerous aftershocks that continued through 1953; 81 of these were of magnitude 3.0 or greater. The earthquakes probably originated on the Mission Creek fault, a major branch of the San Andreas system. The aftershock epicenters are concentrated in a zone 18 km long, parallel to but 5 km north of the fault trace indicated by older scarps. This suggests a 73-degree northerly dip of the fault plane, and the first motions at near-by stations indicate a combination of right-lateral and thrust displacement; both the postulated dip and displacement are consistent with the regional geology. The strain release during the aftershocks is concentrated toward the two ends of the line of epicenters, and the main shock is near the southeast end of this line.

Early arrival times and anomalous *S-P* intervals for some of the shocks at near-by stations remain unexplained, as do abnormal delays at Palomar for many of the shocks.

MAGNITUDE AND INTENSITY SCALES

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Public confusion exists as to the meanings of the terms "Magnitude" and "Intensity". New terms are proposed for the better expression of meanings and the prevention of confusion.

FLOWAGE STRUCTURE IN CENTRAL NEVADA IGNIMBRITES

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Ignimbrites which once covered Battle Mountain and adjacent ranges in Nevada are exposed in erosion remnants about 4 square miles in area.

The ignimbrites are in thick bodies generally consisting of three units that were formed contemporaneously: a basal fragmental unit up to 20 feet thick; a middle vitrophyre 20–30 feet thick;

and an upper aphanitic quartz latite more than 100 feet thick. About 150 feet of material has been eroded. The basal unit is composed of slightly welded fragments of pumice, crystals, and glass. The middle vitrophyre consists of crystals, crystal fragments, and shards that have been highly welded. The upper quartz latite is composed of crystal and crystal fragments with some rock fragments in a matrix of glass and devitrified glass. Shard structure is apparent locally but is generally obscure. The quartz latite shows indistinct layering commonly parallel to the mature erosion surface on which the sequence rests. Some layers are glass with crystal fragments and some rock fragments; others are glass crowded with spherulites and with crystal and rock fragments. Layering was the result of flowage while the rock was viscous.

The ignimbrites are considered to have been erupted as glowing avalanches whose central part was a liquid-solid-gas mixture, surrounded by an expanding envelope of solids and gas. After the material came to rest, the outer part, which was chilled by expansion and contact with air and ground, formed the slightly welded basal unit. The central part remained viscous, and flow structures developed before solidifying.

STRATIGRAPHY OF THE LOWER TO MIDDLE PALEOZOIC CARBONATE SEQUENCE IN THE EASTERN GREAT BASIN

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The 4000- to 7000-foot sequence of carbonate strata between the Eureka quartzite (M. Ord.) and the Pilot shale (Dev.-Miss.) in the eastern part of the Great Basin has been studied throughout approximately 50,000 square miles in southeastern California, southern and eastern Nevada, and western Utah. Although the rocks composing this sequence are superficially similar, marked differences in lithology and organic content can be recognized and traced for great distances. These differences provide a basis for subdividing the sequence into formations that, for the most part, extend with very little change throughout this large area. T. B. Nolan subdivided the sequence at Gold Hill, Utah, into five formations: the Fish Haven dolomite (U. Ord.), Laketown dolomite (Sil.), Sevy dolomite (L. Dev.), Simonson dolomite (M. Dev.), and the Guilmette formation (M.-U. Dev.). Although the sequence at Gold Hill is somewhat atypical, Nolan's subdivision can be applied, with some modification, throughout the entire area. Lateral changes in the beds which overlie the Simonson make it advisable to use the name Sultan limestone rather than Guilmette formation for these beds in southern Nevada and southeastern California.

A zone of major stratigraphic significance extends northeastward from southeastern California, across southern Nevada, into western Utah. This zone marks the southeastern edge of the Paleozoic miogeosyncline (Millard belt). Southeastward across this zone successively younger Devonian beds lie unconformably on successively older pre-Devonian beds. Southeast of this zone the Sultan limestone lies unconformably on rocks of Cambrian age.

APPLICATIONS OF RADON CONCENTRATIONS TO GROUND-WATER STUDIES NEAR SALT LAKE CITY AND OGDEN, UTAH

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Contours of equal-radon concentrations in waters from 130 wells in an area of 15 square miles north of Salt Lake City, Utah, show well-defined, linear highs over two known faults in unconsolidated valley fill. Several additional parallel highs suggest a series of en echelon faults or fractures not otherwise evident from surface expression.

In the North Ogden, Utah, area, where radon was measured in water from 300 wells in 20 square miles, the extension of five faults from bedrock into the area of valley fill is suggested by the alignment of linear zones of high radon concentrations. The randon concentrations range from 250 to 2300 micromicrocuries per liter in the area north of Salt Lake City, and from 100 to 2800 micromicrocuries per liter in the North Ogden area.

An observed regional increase in the general radon background north of Salt Lake City is attributed to a corresponding variation in the sediments in the aquifers. In the low background region (200–300 micromicrocuries per liter) the sediments were derived from sedimentary rocks in the adjacent mountains. In the region of high background (600–800 micromicrocuries per liter) the sediments were derived largely from schists and gneisses.

No correlation was observed in either area between the radon content of the ground water and depth (10 feet to 800 feet) or rate of discharge of the well. In all waters studied radon is unsupported by radium in solution and is essentially constant with time (up to 1 year).

LONGITUDINAL WAVES FROM THE DIXIE VALLEY-FAIRVIEW PEAK EARTHQUAKES

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Two large earthquakes occurred in Nevada slightly more than 4 minutes apart on the morning of December 16, 1954. The first shock originated just east of the surface faulting about 7 km north of Fairview Peak. The second shock originated about 55 km to the north near the Dixie Valley fault. The focal depths, estimated by pP-P, were of the order of 15 and 40 km, respectively. Travel times to about 400 km were noticeably dependent upon the epicenter to station path. Between 500 and 1200 km the times are well represented by a straight-line travel-time curve of slope 1/8.05 seconds per km. Travel times for P at distances greater than 14° were found to be in good agreement with tables published by Gutenberg in 1953.

SEISMIC EVIDENCE FOR THE DIRECTION OF FAULTING IN THE FAIRVIEW PEAK EARTHQUAKE

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The Fairview Peak, Nevada, earthquake of December 16, 1954, provided a unique opportunity for a critical test of the seismic method for determining the direction of motion at the focus of an earthquake. The seismograms were interpreted to indicate a fault striking N.11°W. and dipping 62°E. Both normal and right lateral components of motion were indicated, with the lateral component about twice the normal component. This interpretation agrees with geologic field evidence and geodetic survey data.

LAST MAJOR ADVANCE OF MALASPINA GLACIER, ALASKA

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Malaspina Glacier is a piedmont ice sheet covering 1000 square miles on the flat coastal foreland of southern Alaska. Trees growing in ablation debris on stagnant ice at the outer margin of this sheet and remnants of interglacial forests overridden by the glacier fix the date of culmination of the last advance at 200 ± 50 years ago. Soils and organic debris at the interglacial forest sites indicate that this was the most extensive advance of the Malaspina Glacier in many hundreds if not thousands of years.

NAVY ELECTRONICS LABORATORY DEEP-SEA CAMERA

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Investigation of ocean-floor environmental conditions led to the development of the NEL Type III Deep-Sea Camera which is capable of obtaining 24 bottom photographs on a single lowering to a maximum depth of 20,000 feet.

The design was based on the demand for photographs of important features occurring at depths beyond the limitations of existing under-water cameras and also on the availability of oceanographic vessels equipped only with lighter winches and smaller-diameter wire-lowering ropes.

The camera unit, adaptable to variable depths and operating conditions, consists of a compact water-tight arrangement of a 35 mm Robot Camera, a 2000 volt electronic light source, a connected flash tube with water-flooded reflector, and a small oil-filled tripping switch. A light steel frame holds the water-tight case and junction box which house the photographic and electrical parts in the proper relationship to the ocean floor.

Activation of the tripping switch by bottom contact at 30-second intervals enables the camera to take successive photographs.

Deeper-bottom features of the Continental Shelf, the continental slope, and the abyssal deeps to the west are now being photographed to help reveal the nature of microrelief on the ocean floor, movement and identification of materials settling to the bottom, and the identification and distribution of biological life on, near, and in the bottom sediments.

Photographs obtained with the NEL Type III Camera show the extreme variations in environmental conditions caused by such factors as depth changes and nearness to land.

PEPERITES AS CONTACT PHENOMENA OF SILLS IN THE ELKHORN MOUNTAINS, MONTANA

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Peperites are rocks formed by mixing of magma and moist sediments. Basaltic and andesitic peperites are common in the Late Cretaceous volcanic rocks of the Elkhorn Mountains, Montana, where they form the marginal parts of some thick sills in thin-bedded volcanic mudstone and siltstone. Some thin sills consist wholly of peperite. The peperites are characterized by contorted country rock inclusions in basalt or andesite and by contact breccias of intermixed sill and country rock. Clastic dikes cut this mixture. Strata overlying peperite sills are generally deformed; those above normal sills are not.

Vesicles, now largely filled with secondary minerals, are abundant in the peperites and common in bordering country rock; they are absent in the central part of the sills. The peperite is high in H_2O and CO_2. This, coupled with the localization of vesicles, strongly suggests that water was derived from enclosing rocks.

Magma was intruded into moist, semiconsolidated sediments, disrupting and deforming plastic lumps of sediment and at the same time baking them and driving out water. This water chilled the magma and caused violent steam explosions which brecciated the chilled intrusive and the baked country rock and churned these fragments into the still-fluid part of the magma.

The interpretation that these sills were intruded into moist, semiconsolidated sediments implies shallow depth of cover. If true, the intrusives were approximately contemporaneous with the enclosing strata. A means is thus available to date periods of intrusion closely and to test speculations on migration of intrusive centers and progressive differentiation of source magmas.

GENESIS AND GEOLOGIC ANTIQUITY OF THE MONTEREY SUBMARINE CANYON

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Recent exploratory activities of the oil industry in the Moss Landing area contiguous to the head of the Monterey Submarine Canyon have yielded data to suggest the presence of a deep, sediment-filled ancestral canyon subjacent to the present Monterey Submarine Canyon. Such an interpretation corroborates theories that the Monterey Canyon was subaerially cut, filled by subsequent downwarping, and later reopened by principally subaqueous mechanisms.

SHELL MINERALOGY OF SOME PALEOZOIC INVERTEBRATES

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Two Pennsylvanian formations, the Kendrick shale and the Buckhorn asphalt, preserve calcareous shells in an unaltered condition permitting mineralogical and geochemical study. Mineralogical determinations by stain and x-ray show that aragonite is still present, and thin sections show that in selected material the shell microarchitecture is preserved and recrystallization virtually absent. Preliminary tests of the isotopic composition of oxygen from the shell carbonates suggest that there has been no serious exchange and that paleotemperature determination may be possible.

Together the two formations yield a fauna including mollusks, brachiopods, bryozoans, arthropods, echinoderms, cnidarians, and protozoans. Present small samples suggest that brachiopods, tetracorals, bryozoans, crinoids, echinoids, and trilobites used only calcite in their skeletons, while gastropods, pelecypods, and cephalopods utilize either aragonite alone or discrete layers of calcite and others of aragonite. One nautiloid, *Pseudorthoceras*, contains variable but small amounts of what seems to be original calcite in its cameral deposits. The mineralogic habit characterizing the modern pelecypod groups, Nuculacea, Arcacea, Mytilacea, Pinnacea, and perhaps others, appears to have been firmly established by the Pennsylvanian. Among gastropods the Euomphalacea seem to possess an outer calcitic and an inner aragonitic layer.

The results obtained agree with those of Böggild and suggests that his method can be safely used to extend mineralogic study to older rocks. Aragonite in carbonate sediments may greatly reduce porosity by recrystallization to stable calcite which involves an 8 per cent volume increase. The Buckhorn asphalt contains up to 60 per cent aragonite.

ENGINEERING ASPECTS OF THE DIXIE VALLEY-FAIRVIEW MOUNTAIN, NEVADA, EARTHQUAKE OF DECEMBER 16, 1954

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Although surface geologic evidences and seismographic records pointed to an earthquake of considerable strength, the few structures in the epicentral region suffered relatively little damage. A wood frame structure, located in a graben formed by the earthquake, was undamaged. Also several "nonearthquake-resistive" masonry structures in the area had no serious structural damage.

The most serious structural damage occurred about 185 miles away in Sacramento, California. Water in a reservoir, sludge and water in sewage-disposal tanks, and water in a clarifier tank surged to cause structural damage. Ground motion as recorded by a seismograph located near by indicated that the nearly sinusoidal motion of the ground was close to the natural fundamental periods of the reservoir and the tanks.

VARIATION OF AMPLITUDE WITH DEPTH IN RAYLEIGH WAVES

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The model chosen is a semi-infinite medium with a double surface layer, for which the wave-velocity equation has already been solved for a fair range of wave lengths; the derivation of the amplitudes from the boundary conditions is straightforward but laborious and has been programmed for the SEAC electronic computer. The seismological interest is that if in any particular case the amplitude vanishes at some depth then for a focus at that depth the corresponding Rayleigh waves will not be excited.

ANISOTROPY IN ROCKS UNDER SIMPLE COMPRESSION

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Compressional velocities through samples of several types of rocks have been measured while the samples were subjected to simple compression in a hydraulic press. Velocity measurements were made in directions parallel to and perpendicular to the direction of the compression, with the amount of compression varying from zero up to the rupture point. All measurements were made at room temperature and with no confining pressure other than that of the atmosphere.

Velocities in a direction parallel to the compression increased with compression in a manner somewhat similar to the increase found by other workers in samples subjected to hydrostatic pressures. Velocities in a direction perpendicular to the compression also increased, but at a much lower rate. The differences in the two velocities amounted to more than 10 per cent in some cases.

The differences in velocities are large enough to suggest the possibility of making a rough determination of the state of strain in the neighborhood of a recognized active fault known or suspected to be near vertical. Possible applications toward the prediction of rock bursts are also suggested.

CRUSTAL STRUCTURE IN NORTHERN CALIFORNIA

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Travel times of seismic waves set up by a large quarry blast in Richmond were studied to investigate layer thicknesses and velocities in the upper 10 km of the earth's crust in the San Francisco Bay area. Data of earthquakes with foci above or only slightly below the Conrad Discontinuity at a depth of about 10 km are consistent with the quarry-blast data.

Instrumental data from the Eureka, California, earthquake of December 21, 1954, were used to derive the apparent surface velocity of P_n, along with valleys and Coast Ranges of California, and were entirely consistent with a straight-line travel-time curve between 3° and 10° from the epicenter. The data of this shock are thus inconsistent with recent tables published by Gutenberg, which indicate a decrease in the apparent surface velocity at distances above 6°.

EVALUATION OF BREAKWATER AND JETTY STONE SOURCES, NORTHERN CALIFORNIA

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The San Francisco District, Corps of Engineers, has constructed breakwaters and jetties at Crescent City, Humboldt Bay, Noyo Harbor, Bodega Bay, Moss Landing, and Monterey Harbor and is investigating a breakwater at Halfmoon Bay. Construction and maintenance of these structures require stone that weighs as much as 20 tons, approximately 9 cubic yards, a cube of 6.2 feet. Few quarries on the Pacific Coast can, or will, produce stone that is free of fractures, has high specific gravity and low absorption, and that will resist abrasion for breakwater use. Quarry investigations include geologic studies, subsurface exploration involving seismic, diamond drilling, and quarry-test shot methods, as well as laboratory and petrographic analyses. None of these gives entirely satisfactory results, so the problem resolves itself to one of engineering-geologic knowledge and experience.

Within the District, the principal sources of breakwater stone are in the indurated graywacke and the less basic igneous intrusives of the Franciscan formation and in the Coast Range Santa Lucia and Montara granites. The Franciscan graywacke usually is deeply weathered, severely fractured, contains erratically intercalated black shale or chert, and the harder masses tend to be small. The less basic igneous sills and plugs are better prospecting areas. Granite usually is deeply weathered and severely fractured below the zone of disintegration, so that exploration and opening of a site is expensive. A possible substitute for heavy stone is a four-legged mass of concrete called a tetrapod.

MORAINAL SEQUENCE IN ROCK CREEK-HILTON CREEK DRAINAGE, EASTERN SIERRA NEVADA

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Four morainal sequences are identified in the Rock Creek-Hilton Creek drainage: (1) Oldest deposits are thin, composed of rock flour with well-decomposed iron-stained granitic boulders. (2) Superimposed, but by obscure contact, are thick lateral moraines, continuous on the east side of Rock Creek Canyon and parallelled, though less conspicuously, by similar moraines on the west side of the canyon and along the plateau margin between Rock and Hilton creeks. These moraines extend to the lowest elevations down canyon. (3) Sharp contacts are observed between moraines of (2) and overlying lateral moraines which extend down canyon a shorter distance but with greater prominence. These are likewise present on the east side of Hilton Creek. (4) Small discontinuous lateral moraines and low terminal morainal ridges nestle within the sharp lateral moraines of the preceding sequence, closer to cirque sources in both Rock and Hilton basins.

Dependence of Hilton drainage on the larger Rock Creek drainage in early stages of glacial history is suggested by overlapping of deposits from Hilton and Rock Creek drainages. Source identification is possible because of bedrock differences in the two basins.

COAST RANGE STRUCTURE, KING CITY QUADRANGLE, CALIFORNIA

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Field mapping and data from 30 wells have revealed details of structure across a Salinas Valley area where parts of three structural blocks were studied. The northeast block (Salinas Valley and tableland) is composed of granitic basement thinly blanketed by post-Monterey sediments dipping 2½° SW. The central block (San Antonio Hills) comprises 8500 feet of strongly folded Tertiary sediments (dominantly Monterey shale) overlying granitic basement. It is bounded on the southwest by a zone of vertical to overturned northeast-dipping beds cut by a northeast-dipping thrust near the west quadrangle border. Part of the zone of steep dips forms the southwest flank of a nose which plunges southeast from a complexly faulted basement high; lenses of conglomerate and a local unconformity indicate middle Miocene uplift along this nose. The southwest block (San Antonio Valley lowlands) is characterized by simple folding.

The "King City fault", which separates the northeast and central blocks, is marked by a buried scarp sloping 15°–20° SW. and descending 6000 feet in elevation. Intermittent displacement caused the Monterey shale to abut against the scarp through a zone of shore-line sands. Following a late Miocene disturbance which exposed Monterey shale in or near the quadrangle, major compression (late Pliocene or early Pleistocene) deformed the southwest and central blocks, producing northwest-trending folds involving the Paso Robles and older formations. Wedging up of the central block is indicated along the southwest border and may have occurred along the "King City fault", reversing the direction of earlier movement.

PRELIMINARY REPORT ON THE UPPER TRIASSIC STRATIGRAPHY OF HUMBOLDT COUNTY, NEVADA

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Reconnaissance mapping in northeastern and central Humboldt County, Nevada, has established the presence of Upper Triassic rocks at several localities. These rocks are, for the most part, phyllites, pyllitic slates, and fine-grained feldspathic quartzites, with some carbonate rocks and altered volcanic rocks. On the basis of lithology and meager faunal evidence they are correlated with Triassic units in the Winnemucca quadrangle mapped by Ferguson, Muller, and Roberts.

The Upper Triassic units from oldest to youngest are: (1) a series of dark slates and phyllitic slates

with subordinate fine-grained quartzites, carbonate rocks, and altered volcanic rocks, tentatively correlated with the Grass Valley formation, and separated from younger units by a thrust fault; (2) a series of brown to dark-gray calcareous shales, calcareous and dolomitic slates, carbonate rocks, and sandstones, tentatively correlated with the Winnemucca formation; (3) a series of brown siltstones and fine-grained quartzites with some interbedded shale, believed to be a new formation faulted out of the section in the Winnemucca quadrangle; and (4) a series of light-gray and green phyllites, phyllitic shales, fine-grained feldspathic quartzites, and minor amounts of altered volcanic rocks, with some carbonate rocks near the base, tentatively correlated with the Raspberry formation.

NOONDAY DOLOMITE, JOHNNIE FORMATION, STIRLING QUARTZITE, AND WOOD CANYON FORMATION IN THE SOUTHERN DEATH VALLEY REGION, CALIFORNIA

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The Lower Cambrian Wood Canyon formation and the conformably underlying and essentially unfossiliferous succession composed of the Stirling quartzite, Johnnie formation, and Noonday dolomite are well exposed in hills along a 20-mile belt extending from the southern part of the Nopah Range southward to the Garlock fault which marks the northeastern margin of the Avawatz Mountains. Detailed mapping within this belt shows that the major lithologic subdivisions, recognized by Hazzard in the Nopah Range, are persistent.

From north to south, the Noonday dolomite apparently thins and pinches out, and the Johnnie formation, Stirling quartzite, and Wood Canyon formation decrease in combined thickness to about 3800 feet or slightly less than half their thickness in the southern Nopah Range. The occurrence of these three formations at the southern end of the belt, however, suggests that the basin of deposition extended well southwest of the near-by trace of the Garlock fault.

A remarkably persistent oölite layer high in the Johnnie formation everywhere lies within 200–350 feet of the base of the Stirling quartzite, a relationship that argues against a previously suggested unconformity between the two formations.

ABSTRACTS OF PAPERS SUBMITTED FOR THE MEETING IN ALBUQUERQUE, NEW MEXICO, MAY 4, 5, 1956

ROCKY MOUNTAIN SECTION (GSA)

ARTESIAN AQUIFERS OF THE UPPER JAMES RIVER VALLEY, BROWN COUNTY, SOUTH DAKOTA

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Upper James River Valley, in Brown County, northeastern South Dakota, is geologically situated in the plain of glacial Lake Dakota. The region is underlain by aquifers of the Dakota Group at depths of 903 to 1260 feet below land surface.

The aquifers of the upper part of the Dakota Group are not separate and distinct from each other, but the lowest aquifer is separate and distinct from all others. This conclusion is based on drillers' logs and analyses of the mineral content of the waters.

A structure-contour map on the top of the Greenhorn formation is presented; the contour interval is 20 feet. The Greenhorn appears as a consistent marker on electric and drilling logs at depths of 452 to 720 feet below land surface. The top of the Greenhorn is believed to be essentially parallel to the top of the Dakota Group.

TITANIFEROUS CRETACEOUS BEACH PLACER IN MCKINLEY COUNTY, NEW MEXICO

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Microscopic and X-ray analysis shows that a specimen of radioactive sandstone, submitted to the Bureau for identification, is exceptionally rich in brookite, rutile, anatase, and leucoxene. These titanium minerals make up as much as 40 per cent of the rock. Radioactive zircon occurs in amounts sufficient to produce a reading of two to four times normal background on a geiger counter. Quartz, magnetite, ilmenite, and clayey material constitute most of the remainder of the sandstone. Quartz content is less than 10 per cent in some samples.

The titaniferous sandstone can be distinguished in the field from the other sandstones of the Mesaverde group by its peculiar olive-green (10Y6/2) color, marked with irregular reddish streaks, and by its high specific gravity. Five miles west of Gallup, this rock caps the massive cliff-forming middle member of the Gallup sandstone (upper Carlile?), just below the Myers or Richards coal seam (Sears, 1925). The titaniferous sandstone is less than 4 feet thick, its outcrop width is seldom more than 100 feet. It was traced for about 1000 feet in a N. 25° W. direction, a trend nearly parallel to that of the Dilco shore line sketched by Sears (1941).

Mineral association and field occurrence suggest that an originally ilmenite-rich black-sand beach placer was altered, with removal of iron and relative increase in titanium content. As evidence of hydrothermal activity is lacking, it is tentatively suggested that ground water in the zone of oxidation produced the alteration.

If the titanium content of this rock can be utilized, prospecting for similar placers elsewhere in the San Juan Basin might prove worth while.

PENNSYLVANIAN AND PERMIAN CORRELATIONS IN THE CORDILLERAN AREA

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Throughout much of the Cordilleran area embracing parts of Utah, Nevada, Idaho, Oregon, California, and part of Arizona many of the formations of Pennsylvanian and Permian age can be corre-

lated with certain degree of accuracy, more on paleontologic than on lithologic basis. Essentially all the strata of Pennsylvanian age are of marine origin; some are metasediments. Most of the Permian rocks are marine sediments, although many localities contain thick sequences of interbedded volcanics and volcanic-derived materials. Thus, both the miogeosynclinal and eugeosynclinal facies are distinguished in both systems.

Fusulinids permit wide-range correlations. Using the thick Oquirrh formation section in the south-central Wasatch Mountains of Utah as a standard, faunal zones of comparable age can also be recognized in numerous other places. Rocks representative of all series of the Pennsylvanian (Springeran through Virgilian), as well as much of the Permian Wolfcampian, Leonardan, and Guadalupian are present, although not complete at all localities. The Great Basin contains numerous sedimentary basins and complementary highs. The present study demonstrates that detailed studies of lithologies complementing the paleontologic investigations enable the stratigrapher to extend nomenclature of certain lithic units beyond previously determined geographic boundaries.

DISTRIBUTION AND TECTONICS OF THE MOUNT OLYMPUS GRANITE, FRONT RANGE, COLORADO

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The Mount Olympus granite crops out widely in the Precambrian mosaic of granite, metasedimentary, and meta-igneous formations of the Front Range, Colorado. It is satellitic to the Silver Plume type granite and, with that granite and their genetically related aplites and pegmatites, constitutes the younger Precambrian batholiths and a number of smaller plutons.

The Mount Olympus granite was recognized as a distinctive Precambrian granite within the Longs Peak-St. Vrain batholith in 1924 and was named for Mount Olympus east of Estes Park where it is well exposed. The light-gray color, haphazard "pepper and salt" texture, and small pluton habit of the Mount Olympus granite contrast with the pink to tan color, trachytoid and subporphyritic texture and large pluton, massive habit of the Silver Plume granite which is usually its host.

The Mount Olympus granite occurs within and fringing the Log Cabin, Kenoska, Silver Plume, and Cripple Creek batholiths and the Indian Creek plutons. Dikes of it intrude the older Precambrian granites and the Idaho Springs and Swandyke formations. Lenses, pods, and irregular bodies of the Mount Olympus granite make up the apical and marginal portions of the larger granite masses and fill finite fractures in both granites and tightly folded schists and gneisses.

Zoned pegmatites of Mount Olympus origin occupy portions of several strongly developed northwest-trending faults that originated in Precambrian time and were reactivated by shearing as recently as Laramide time.

THRUST FAULTING IN THE TETON RANGE, WYOMING

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Recent studies of the Precambrian complex of the Teton Range, Wyoming, have revealed the presence of three or four high-angle thrust sheets in the vicinity of Death Canyon and Buck Mountain. The fault planes range in dip from 30° to 80°, generally southeast, and large drag folds adjacent to the fault surfaces indicate the direction of movement. Displaced Cambrian sediments along one of the faults and the fresh unconsolidated gouge suggest a Laramide date for the faulting. However, minor crumpling of the gneissic rocks associated with en echelon, podlike intrusions of Precambrian diorite, together with later intrusions of Precambrian pegmatite into tensional gashes indicate movements in the same general direction in Precambrian time. It therefore seems likely that Precambrian movements produced the initial crustal weaknesses and predilection which guided some of the later Laramide movements.

SUBMARINE ABRASION AND WAVE-CUT PLATFORMS

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A modern wave-cut platform, 1½ miles wide at Santa Cruz, California, is thinly veneered by neritic deposits. Important abrasion of fragile pyroxene sand grains included in these deposits is re-

stricted to approximately the inner half mile of the platform where the water is less than 30 feet deep. Numerous fragile pyroxenes at depths greater than 30 feet suggest that the deeper deposits are not suffering significant abrasion and are not abrading the underlying platform. It is concluded that geologically significant submarine abrasion is limited to the surf zone, the maximum depth of which is about 30 feet; that, with wave conditions and bedrock similar to those of the Santa Cruz area, a platform up to about half a mile in width may be cut by a sea with a stationary level; and that, for a platform wider than half a mile to be cut, sea level must be rising during erosion. These conclusions do not agree with the long-standing belief that broad wave-cut platforms are produced by relatively deep submarine abrasion while sea level is stationary.

SEDIMENTARY ENVIRONMENTS OF THE DAKOTA FORMATION IN NORTHWESTERN COLORADO

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Field and laboratory studies suggest that basal Cretaceous rocks of the Dakota formation in northwestern Colorado are lithogenetically related to similar strata east of the Front Range. The sequence of sandstone and light and dark shales represents a transition from continental to marine deposition near the shore line of the Cretaceous Rocky Mountain exogeosyncline.

Subdivision of the sequence into three widespread units is possible: a basal conglomeratic sandstone, a middle shale and shaly sandstone, and an upper sandstone. Correlation of stratigraphic details, especially within the middle unit, is not possible because of abrupt lateral variation.

Conglomeratic texture, moderate to good sorting, cross-bedding, channeling, cut-and-fill structures, and association with pastel-colored shales suggest a fluvial origin for the lower sandstone unit. Chert pebbles containing Paleozoic fossils imply a western source for the detritus of this unit. The middle unit, characterized by gray and black highly carbonaceous shales, shaly, carbonaceous sandstones, coal, and irregular, discontinuous bedding, is attributed to paludal and lagoonal deposition. Well-sorted fine sand, lack of distinctive primary structures, widespread homogeneity, and gradational contact with overlying marine shales indicate a shallow neritic environment for the upper sandstone. Highly strained metamorphic quartz grains suggest an eastern source of detritus for the upper unit. Considerable variation exists within the general patterns of environment.

LIMESTONES AND EVAPORITES OF THE LYKINS FORMATION, FRONT RANGE OF COLORADO

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Six limestone units and three zones of gypsum are present in the red beds of the Lykins formation (Permo-Triassic) in northern Colorado along the east flank of the Front Range. The four uppermost limestones are correlated (ascending) with the Minnekahta limestone, the Forelle limestone, and two previously unnamed limestones of the east flank of the Laramie Range in Wyoming. The two lowermost limestone units are of local extent only. The Forelle limestone and a limestone bed at the base of the Minnekahta are correlated with the Glennon and Falcon limestones, respectively, of the Golden, Colorado, area, and they extend southward beyond Colorado Springs, Colorado.

Gypsum lenses, 10–25 feet thick, are present in northern Colorado between the Lyons sandstone and a southerly extending tongue of the Minnekahta, between the southerly extending tongue of the Minnekahta and the Forelle, and within the Forelle.

The correlations presented permit a revision of the nomenclature.

STREAM CHANNELS AND URANIUM MINERALIZATION OF THE SHINARUMP CONGLOMERATE, CIRCLE CLIFFS, GARFIELD COUNTY, UTAH

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The Circle Cliffs anticlinal upwarp, just west of the Henry Mountains in Garfield County, Utah, is an asymmetrical fold breached by erosion, whose east limb passes into a major monocline called

the Water Pocket fold. The sedimentary rocks range from the Permian Coconino sandstone to the Jurassic Navajo sandstone.

The only known commercial concentrations of uranium minerals are in stream-channel-type deposits of the Triassic Shinarump conglomerate. This formation consists of fine- to coarse-grained quartz sandstone, siltstone, claystone, and local conglomerate lenses. The thickness is 25–60 feet in areas where stream channels are not present. An erosional unconformity at the base of the Shinarump is expressed by major and minor stream channels incised into the Triassic Moenkopi formation. The channels were then filled with the fluvial Shinarump deposits.

Three types of channels formed by the Shinarump streams cutting the Moenkopi surface have been recognized: (1) shallow, wide "flood-plain" type, 25–60 feet thick and more than a mile wide; (2) the wide, deeply incised "trunk river" type, 60–245 feet thick, half a mile to a mile wide; and (3) the "tributary and distributary" type, 60–100 feet thick and about 500 feet to half a mile wide.

Stream channels and their trends were recognized and plotted from channel outlines, variation of formational thicknesses, and intraformational structures such as cross-bedding, ripple marks, and current lineation. The general direction of flow of the streams was northwest and west.

Uranium mineralization is confined primarily to stratigraphic traps formed along channel lows, flanks, and fringe areas. These traps are developed by interlensing or intermixing of sands, silts, muds, and wood fragments. Uranium occurs as fillings and replacements of these materials and on occasion occurs along structural traps such as slumps and faults. The mineralization has resulted from uranium-bearing solutions that were impeded along zones of relatively low porosity and/or permeability.

Uraninite, tobernite, carnotite, and autunite are the principal ore minerals. Associated gangue minerals include azurite, malachite, chalcopyrite, pyrite, and arsenopyrite.

RADIOACTIVE TITANIFEROUS HEAVY-MINERAL DEPOSITS IN THE SAN JUAN BASIN, MEW MEXICO AND COLORADO

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Numerous titaniferous black-sand deposits have been discovered at several localities in the San Juan Basin of New Mexico and Colorado. They occur in the upper parts of massive, well-sorted regressive Upper Cretaceous littoral marine sandstones.

The deposits form resistant, iron-stained, elongate lenticular zones, containing ilmenite and its alteration products hematite and anatase, garnet, zircon, tourmaline, magnetite, rutile, monazite, and several unidentified opaque minerals believed to contain rare earths.

Radioactivity, which has led to discovery of many of the deposits, is attributed to uraniferous zircon, thorium, and rare earths. Chemical and radiometric analyses show a maximum of 0.010 per cent uranium and 0.051 per cent equivalent uranium. The titanium content, up to 32 per cent in some of the deposits, may possibly be of some value.

Radioactivity, characteristic sedimentary environment and fluorescent zircon will simplify recognizing similar deposits in the San Juan Basin and adjacent areas of Upper Cretaceous rocks.

BROCKTON-FROID FAULT ZONE IN NORTHEASTERN MONTANA

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A half-mile-wide fault zone extends northeastward for 35 miles from Brockton to Froid in Roosevelt County, Montana. The zone was discovered during geologic mapping in surficial deposits and was verified by a series of auger holes across the structure. A vertical displacement of 75 feet of strata was determined at Brockton, and as much as 200 feet is indicated 12 miles to the northeast by structure contours drawn on the top of the Greenhorn formation of Cretaceous age. The fault zone may have been the locus of several earthquakes recorded in the area. Evidence of faults parallel and closely adjacent to the fault zone has been recognized on air photographs.

WATER SAMPLING AS A GUIDE IN THE SEARCH FOR URANIUM DEPOSITS

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Analyses for uranium content, of more than 1000 water samples from sedimentary rocks ranging from Late Cretaceous to Pliocene in age in the Rocky Mountain and Great Plains provinces, have helped to delimit areas for uranium prospecting. Largely on the basis of these analyses, areas previously thought not favorable for uranium have been recommended for prospecting and subsequently found to contain commercial deposits.

Samples were collected from three sedimentary terranes: (1) areas underlain by volcanic and tuffaceous rocks; (2) areas of nontuffaceous fluviatile arkosic sandstone and shale; and (3) areas containing known uranium deposits.

Most ground water from nontuffaceous fluviatile Tertiary sedimentary terranes contains less than 2 parts per billion uranium. Underground water in volcanic and tuffaceous terranes and in areas of uranium deposits may contain 10–250 parts or more per billion. The units of Oligocene and Miocene age, irrespective of their geographic location, had significantly high uranium content in ground water issuing from them.

Brief consideration is given to trace-metal suites determined by chemical analyses of residues obtained by evaporation of bulk samples of water from the better-known and more widely distributed Tertiary volcanic units.

Regional variations in the uranium content of water have two possible applications: (1) to indicate areas where abnormally high uranium content of water reflects present-day leaching of hidden ore deposits; (2) to help evaluate the relative potentialities of widespread volcanic units which may have been an important primary source of uranium later concentrated in the underlying sedimentary rocks.

STRUCTURAL RELATIONS AT THE MONUMENT NO. 2 MINE, APACHE COUNTY, ARIZONA

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The Monument No. 2 uranium-vanadium deposit, in Monument Valley, Apache County, Arizona, is in Shinarump conglomerate (Upper Triassic). Locally the Shinarump fills an ancient stream channel cut through the Moenkopi formation (Triassic) and the Hoskinnini tongue of the Cutler formation (Permian) into the De Chelly sandstone member of the Cutler formation.

Tyuyamunite, carnotite, becquerelite, corvusite, hewettite, metahewettite, rauvite, and uraninite are the principal ore minerals. They impregnate sandstone, fill fractures, and replace quartz, clay, and fossil plant fragments.

The structural features lead to the interpretation that, during the Laramide orogeny in late Cretaceous or early Tertiary time, movement along the bedding planes brecciated the channel-filling rocks. Resistance of the thicker channel sediments to the bedding-plane slippage set up stresses that formed a zone of en echelon strike-slip vertical faults along the channel length. The ore-bearing solutions may have risen along the vertical faults from a deep source and spread out to deposit ore in the highly permeable brecciated sandstone and conglomerate. Upward movement of the solutions was retarded by the lenticular relatively impermeable clayey siltstone that overlies the ore deposit.

Zones of en echelon strike-slip faults cutting post-Moenkopi sedimentary rocks in Monument Valley may be an indication of buried channels and of ore deposits within the channels. Additional tectonic studies in the area will be necessary to test this structural interpretation.

MONTOYA-BIGHORN-RICHMOND CORRELATIONS

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Boreal faunas with intervening austral ones supply the main criteria for Black River, Cobourg, and Richmond beds in eastern North America. The succession, formerly ascribed to successive

wedges of sediments, is today interpreted as contemporaneous interfingering facies. It is suggested that boreal faunas are tropical, austral ones temperate. Boreal advances then represent periods of warmth. Migration involves some selection, mainly by physiological adaptation. Selection and other factors cause ranges of boreal types to be increased as the reservoir area is approached. Some migrants may join the austral faunas. Evidence of these theoretical conditions is found. Theoretically, a complete succession, difficult to zone from previous criteria, may be expected; but interruption of sedimentation may occur without paleogeographic or epeirogenetic changes.

The Montoya, Fremont, Big Horn successions, continuing north to the Ordovician of Winnipeg and Hudson Bay, show striking similarities. The succession involves (1) a basal sandstone that is anomalous faunally and is at least as old as the Black River; (2) local basal sands, and limy beds, with faunal successions of Red River aspect; (3) limes above with Richmondian faunal successions. To the north, the expected mingling of Red River and Richmond types is found. At the south the two are much more distinct. There, the Richmondian succession includes most of, if not all, the type Richmond. The underlying Red River is to be correlated with late Trenton or Covington. Faunal migrants suggest equivalence to late Trenton and Eden and not to Maysville beds.

GEOLOGY OF THE LOS ALAMOS AREA, NEW MEXICO

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The Los Alamos area is in north-central New Mexico on the western margin of the Rio Grande depression. Volcanic and sedimentary rocks of late Tertiary and early Quaternary age are exposed in the area. The volcanic rocks include an older suite consisting of quartz latite and pyroxene andesite which is of late Tertiary age; and a younger suite consisting of rhyolite tuff and rhyolite domes which is of early Quaternary age. Both suites form a part of the Jemez Mountains volcanic pile which is located on and related in origin to the fault zone at the western margin of the Rio Grande depression. Sedimentary rocks, referred to the Santa Fe group, are present in the Rio Grande depression. These rocks include arkosic sandstone, siltstone, and volcanic debris. Some basalt flows are also referred to the Santa Fe group.

Mapping and subsurface work indicate that all the rocks are complexly interrelated. Mapping indicates that two units of the Santa Fe group interfinger. Subsurface work indicates that two units of the Santa Fe group interfinger with the older suite of flows of the Jemez volcano.

LATEST CRETACEOUS AND EARLIEST TERTIARY ROCKS BETWEEN CASTLEGATE AND GREEN RIVER, UTAH

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Latest Cretaceous and earliest Tertiary rocks in the Book Cliffs region between Willow Creek near Castlegate, Utah, and Tuscher Canyon, east of the Green River, measured at four points of easy access, are compared with an unpublished section measured by C. E. Erdmann in Horse Canyon, 6 miles south of Sunnyside, Utah, and with the published section by E. M. Spieker and J. B. Reeside on the Green River south of Desolation Canyon. Identification of a unit characterized by beds of lacustrine limestone in all sections affords a basis for comparing stratigraphic nomenclature used by previous workers in the area.

The part of the Price River formation above the Castlegate sandstone member is 1600 and 1800 feet thick, respectively, along Willow Creek in the westernmost section and Tuscher Canyon in the easternmost section, and thins to 220 feet in the Soldier Canyon section, 12 miles east of Willow Creek. Sections at Whitmore Canyon (Sunnyside, Utah), Horse Canyon, and along the Green River have intermediate thicknesses. Possible crustal warping in this area during the last Montana pulses of the Laramide orogeny is suggested by these rather abrupt changes in thickness.

West of the Green River the Price River formation is overlain conformably by the partly lacustrine unit not separately mapped by previous workers. The lithology of the unit is comparable to the North Horn formation of the Wasatch Plateau, although a thin series of beds at the top in the westernmost

section resembles the Flagstaff limestone. At Tuscher Canyon east of the Green River, the partly lacustrine unit overlies a conspicuous conglomerate that in turn overlies the type Tuscher formation of Fisher.

The Colton formation thickens southward, and possibly eastward, by intertonguing with the overlying Green River formation. The stratigraphic magnitude of the intertonguing is indicated by thin oölitic limestone beds, representing tongues of Green River, which occur as much as 1650 feet below the base of the main body of the Green River at Whitmore Canyon.

LATE MESOZOIC GRANITIC ROCKS OF CENTRAL CALIFORNIA

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The granitic rocks of late Mesozoic age (Nevadan) of central California form the Sierra Nevada batholith, trending north-northwest for 350 miles, and numerous small batholiths and stocks in the ranges to the east. The main batholith is oblique to the contact, in northern Nevada and eastern California, between early Paleozoic eugeosynclinal and miogeosynclinal belts; the western part of the batholith is marginal to a late Paleozoic to early Mesozoic eugeosynclinal belt. Regional metamorphism of low to middle grade preceded emplacement of the granitic plutons, and emplacement was accompanied by contact metamorphism.

The Sierra Nevada batholith is composed of hundreds of separate plutons; adjacent plutons may be of widely different composition, but the average composition changes irregularly eastward from quartz diorite to quartz monzonite. The abundance of hornblende gabbro, diorite, and quartz diorite roughly parallels that of basic metamorphic rocks, and where basic metamorphic rocks are lacking so are basic plutonic rocks. This, considered with field relationships, indicates that the basic plutonic rocks formed largely by assimilation of basic metamorphic rocks in silicic magmas.

East of the Sierra Nevada, granitic rocks, dominantly quartz monzonite, intrude Precambrian basement rocks as well as sedimentary rocks; these granitic rocks must have crystallized from magmas formed beneath the geosyncline.

PARAGENESIS OF THE TEMPLE MOUNTAIN URANIFEROUS ASPHALTITES

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Paragenetic study favors a post-ore, partly petroliferous origin for the uraniferous asphaltites in the Moss Back member of the Triassic Chinle formation at Temple Mountain, Emery County, Utah. The prior U_3O_8 mineralization occurred as (1) replacements within lignitic and silicified wood, (2) concretionary nodules around centers of lignite, and (3) impregnations in sandstone rich in nondescript plant debris. Most of the primary minerals are closely related in time. Early uraninite, montroseite, sphalerite, and galena were closely followed and partially replaced by later native arsenic, tennantite, chalcopyrite, pyrite, and marcasite. Detrital quartz was partly replaced by the metallic minerals, which were later partly replaced by bitumens. Both liquid and solid bitumens originated as petroleum fractions genetically unrelated to local organic remains.

Penetration along ore zones by asphaltic bitumens resulted in selective replacement of both humic and metallic constituents. Lignitic wood was replaced by asphaltite, leaving little or no trace of former cell structures. Asphaltite nodules are pseudomorphic after concretions of uraninite and associated minerals. Their chemical composition is representative of the replaced minerals and may vary considerably. Asphaltic pseudomorphs are not true minerals but rather mineraloids whose variable composition reflects the nature of the host minerals.

The radiation effects of uraninite on hydrocarbons is believed responsible for both the corrosive nature and the polymerization of petroleum fractions. Irradiated hydrocarbons are activated by fragmentation and ionization of molecular groups. The resulting unsatisfied bonds are satisfied by either recombination with other ionized groups (*i.e.*, polymerizarion or condensation) or by reaction with metallic compounds to form metallo-organic complexes. The nature of such bitumens is further diversified by hybrid humic-asphaltic complexes.

STRATIGRAPHIC RELATIONS OF UPPER PENNSYLVANIAN AND LOWER PERMIAN ROCKS IN SOUTHERN PART OF SACRAMENTO MOUNTAINS, NEW MEXICO

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The writer described the stratigraphic relationships of the lower Permian Hueco formation with the Abo formation, in the southern part of the Sacramento Mountains. In general, the dominantly calcareous and marine Hueco formation passes northward into continental red beds of the Abo formation. However, a tongue of the lower part of the Abo formation extends southward below the Hueco formation at least as far as Culp Canyon. This tongue is locally discontinuous owing to the presence of small areas of strongly folded and uplifted rocks in fold belts that developed in late Pennsylvanian time. These areas of late Pennsylvanian uplift appear to have been sources of sediments during late Pennsylvanian and early Permian time. Locally, several hundred feet of limestone pebble and boulder conglomerate has been derived from the areas of uplift and deposited in late Pennsylvanian and early Permian basins. In consequence, the contact of the Abo-Hueco sequence with the underlying Pennsylvanian rocks varies within short distances from one of angular unconformity to one of disconformity. The contact of the Abo-Hueco sequence with the overlying Yeso formation of Permian age is gradational. The Hueco formation grades and intertongues upward with red beds tentatively termed Upper Abo but which are closely allied genetically with the Yeso formation.

LATE CENOZOIC HISTORY OF THE SIERRA NEVADA, CALIFORNIA-NEVADA

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Paleobotanical evidence shows that in Miocene time highest elevations in the Sierra Nevada were about 3000 feet whereas today they exceed 14,000 feet. Broad, mature valleys had been eroded into the lower slopes, while near the crest canyons between low peaks were young, shallow, and widely flaring. Later in the Miocene and early Pliocene, a long, dominantly explosive volcanic episode covered large sections of the northern half of the range with mudflows. Considerable elevation, possibly doming of a greater area than the Sierra Nevada itself, occurred during and following this cycle, allowing erosion of canyons 1200 to 1500 feet deep. During the late Pliocene, the major elevation of the Sierra Nevada occurred, and greatly invigorated streams started erosion of the canyons of the present cycle. A broad dome seems to have developed, extending from the west base of the Sierra Nevada at least as far as the ranges on the east side of Death Valley. The north-south limits are unknown. Simultaneously with elevation, the dome fractured along lines extending west of north; these may in part have been developed during the earlier Pliocene deformation. Grabens were depressed, among which are Carson, Owens, Panamint, and Death valleys.

McGee moraines, believed to be of Nebraskan age, indicate that the Sierra Nevada and probably other ranges within the limits of the dome attained approximately their present elevation prior to the first glaciation. Dislocation of McGee moraines on the east side of the Sierra Nevada shows that graben subsidence of at least 3000 feet followed the first glacial age and is still continuing.

STRUCTURAL GEOLOGY OF THE BROWNE LAKE AREA, NORTHERN BEAVERHEAD COUNTY, MONTANA

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Browne Lake area includes 150 square miles and extends from the east slope of the Pioneer Mountains 15 miles eastward across the Big Hole River valley. Big Hole River flows south along the axis of a gentle synclinorium. On the east side of the area pre-Beltian metamorphics, Cherry Creek (?) group, are overlain with angular unconformity by Paleozoic rocks. On the west granodiorite of the Pioneer Mountains batholith intrudes Paleozoic rocks.

Most prominent structural units are the shallow synclinorium extending east-west throughout the area; northwest-trending folds overturned to the east; northwest-trending high-angle thrusts; a northwest-trending low-angle thrust; high-angle transverse strike-slip and oblique strike-slip faults;

and gentle folds in Tertiary lavas. High-angle thrusts dip 30°–50° SW., and the low-angle thrust (Beal's Mountain klippe) dips 4°E. These structures have been produced in the above sequence.

Youngest rocks affected by overturned folds and high-angle thrusts are Upper Cretaceous (Colorado group). Low-angle thrusting followed, because the thrust plane break is clean cut and clearly truncates crests of overturned folds and high-angle thrust planes (Pennsylvanian Quadrant quartzite is thrust over Upper Cretaceous rocks). These structures are Laramide. Chronology of these structures is hanging on post-Colorado time, hence events are not assigned to specific Laramide phases. Basal Kootenay and basal Colorado conglomerates indicate pre-Laramide uplift, probably to the west.

Axial planes of overturned folds dip inward toward each other (wedge folding) in the western part of the area. Two-sided characteristics of the wedge-folding developed from piling up of Paleozoic and Mesozoic rocks prior to thrust faulting.

UPPER CRETACEOUS AND TERTIARY STRATIGRAPHY OF RATON BASIN OF NEW MEXICO AND COLORADO*

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A thick sequence of Upper Cretaceous and Tertiary sedimentary rocks is preserved in the Raton basin. These strata include the Pierre shale, Trinidad sandstone, and Vermejo formation of Late Cretaceous age; the Raton formation of Late Cretaceous and Paleocene age; the Poison Canyon formation of Paleocene age; the Cuchara and Huerfano formations of Eocene age; a conglomerate of probable Oligocene age; and a formation of probable Miocene age. Some of the events of Laramide deformation are recorded in the rocks of these formations.

Laramide deformation began with epeirogenic movements west of the Raton basin in late Montana time. The epeirogenic movements were followed by at least seven orogenic episodes, as shown by angular unconformities and lithologic changes in the sedimentary rocks.

Sills, dikes, plugs, stocks, sole injections, and laccoliths were intruded into the sedimentary rocks of the basin during the Eocene epoch.

DEFINITION AND ANALYSIS OF BED THICKNESS

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"Thick" and "thin" applied to bedding are terms that are relative to one's stratigraphic training and experience and relative to the associated strata. The terms, "thick-bedded," "medium-bedded," and "thin-bedded" should not be used without definition, although undefined usage is common in the current literature. Recent efforts to standardize the limits of "thick," "medium," and "thin" for bedding are in considerable disagreement.

Standardization or pigeon holing of thicknesses may be necessary only for statistical treatment of stratification. However, in such studies mean bed thickness, thickness frequencies, and other statistical indices may serve better to describe and understand the origin of the assemblage. Many formations possess stratification facies (phyllofacies) as well as biofacies, and lithofacies. It may be just as productive to determine regionally the stratification indices or ratios as it is to study sand-shale ratios. It may be possible and useful to construct regional isophyllos (isobed) maps just as it is to construct isolith maps.

It is proposed that the beddedness of sedimentary units be expressed by the following index

$$\text{Stratification index} = \frac{\text{no. of beds} \times 100}{\text{thickness}}$$

The task of determining, measuring, and counting individual beds is large and subjective. However, it may be a partial sampling just as sampling for lithology and chemical composition commonly is. The writer is convinced on the basis of the quantitative and statistical approach to bed thickness that the additional effort involved yields a much better awareness and appreciation of the nature and significance of bedding.

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LATE CRETACEOUS AND EARLY TERTIARY OUTCROPS OF JORNADA DEL MUERTO, NEW MEXICO*

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Intermediate volcanic rocks and/or associated reddish to purplish sediments overlie Paleozoic and Mesozoic strata in south-central New Mexico and underlie thick Cenozoic volcanic and bolson deposits. Isolated outcrops of these volcanic red beds on Jornada are in dissected areas and near bordering ranges.

Baca formation (Eocene ?) near Carthage, unconformable on Mesaverde sandstone, consists of red calcareous sandstone and siltstone and is overlain by grayish latitic pyroclastics of Datil formation.

McRae formation between Fra Cristobal and Caballo mountains, unconformable on Mesaverde sandstones, includes a lower Jose Creek member of greenish-brown shales and sandstones and andesitic agglomerates. Upper Hall Lake member is purplish and chocolate-brown tuffs and siltstones, light-gray tuffaceous arkosic sandstones, and quartzite-andesite conglomerate lenses. Lower beds are latest Cretaceous and are involved in thrust faulting considered Laramide age.

Near Aleman, thin andesitic sandstones and tuffs overlie Mesaverde sandstones, are overlain by thick red calcareous andesitic sandstones and siltstones, which underlie grayish rhyolite-latite pyroclastics at Point of Rocks. Lower rocks may be McRae; medial red beds may have a common source with Palm Park formation which outcrops in southwest Caballo Mountains and on Rincon and San Diego Mountains. Upper pyroclastics resemble Thurman formation of Caballo Mountains (early Miocene ?).

McRae formation was deposited in latest Cretaceous and possibly earliest Tertiary time penecontemporaneously with Laramide orogeny. Baca, Palm Park, and "Aleman" red beds are early Tertiary, probably pre-middle Miocene. Their nonvolcanic materials were derived from sources west of Jornada, probably from uplifts associated with Rio Grande Trough trend, and suggest initiation of block faulting in early Tertiary time.

GEOLOGY OF THE SOUTHERN BLACK RANGE AREA, GRANT, LUNA, AND SIERRA COUNTIES, NEW MEXICO*

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The Black Range, south of 33°00′ N. Lat., is a faulted anticlinal arch, consisting of volcanic strata unconformably overlying a complexly faulted and intruded maze of Precambrian blocks and about 2500 feet of Paleozoic strata.

Tertiary and Quaternary rocks, in chronologic order, include: (1) fanglomerate; (2) andesite and latite flows, tuffs, and breccias; (3) intrusive quartz monzonite porphyry; (4) sedimentary-volcanic facies (probable age late Miocene-early Pliocene), gradational over lower volcanics; (5) rhyolitic tuffs, flows, and small intrusives; (6) fluviatile and lacustrine sediments dated within limits as early Miocene-early Pliocene; (7) basaltic andesite and latite flows and tuffs; and (8) Santa Fe, Gila, and Mimbres alluvial sediments (Pliocene-Pleistocene) interbedded with thin basalt flows and a quartz latite tuff.

High-angle faults with dominant vertical movement, which began after deposition of the earliest volcanic rocks and continued sporadically into Quaternary time, may be divided into those of east-west trend and relatively later northward-trending faults parallel to the range. The few open folds, which include Tertiary volcanic rocks, are associated with igneous intrusions, are of short extent, and may be adequately explained as a by-product of Tertiary faulting and intrusion. The uniform thickness of the thin upper volcanic series capping the range and forming the peripheral foothills indicates that the principal uplift of the range occurred after early Pliocene time. A belt of Santa Fe group sediments extending across the divide in the southernmost range demonstrates a definitely later uplift, possibly Pleistocene in age.

* Publication authorized by the Director, New Mexico Bureau of Mines and Mineral Resources.

GEOLOGY OF THE WESTERN OWL CREEK MOUNTAINS, WYOMING

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The Owl Creek Mountains, an east-trending range in west-central Wyoming, rise between the Bighorn and Wind River basins. The sedimentary rocks in the western part of the range aggregate more than 15,000 feet in thickness and lie on a Precambrian basement complex of metasedimentary and igneous rocks.

During Paleozoic and Mesozoic time foreland-type sandstones, shales, and limestones accumulated in a generally conformable sequence. As the mountain arch rose during Paleocene and early Eocene time tectonic sediments were shed from it into the flanking basins. Finally, the area was buried under 4000 feet of middle Eocene to Oligocene volcanic sedimentary rocks.

Deformation followed regional fracture zones that transect lithologies and foliation of the Precambrian rocks. The northwest-trending folds in the stratified rocks were formed by draping over east-dipping high-angle reverse faults in the basement rocks. These structures are offset by the east-trending Owl Creek fault zone that passes along the crest of the major uplift. The persistence of the northwest-trending asymmetric folds across the range and adjacent basins indicates that the deformation cannot be accounted for by the "basin-mechanics" hypothesis.

The volcanic rocks comprise a thick blanket of coalescent alluvial fans made up of pyroclastic debris emitted from many local vents. The rocks in the three groups of vents range from olivine-bearing basalt in the middle Eocene sequence to hornblende andesite in the upper Eocene, and biotite dacite in the Oligocene.

MIGRATION OF THE COLORADO FRONT RANGE DRAINAGE DIVIDE

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The drainage divide of the Colorado Front Range did not coincide with the present Continental Divide in early Tertiary time. The former divide extended northwest from Pikes Peak through the Tarryall Mountains, Mt. Evans, and Grays-Torreys peaks, thence northeastward to James Peak, thence northward through Mt. Audubon, Longs Peak, and the Mummy Range to Bald Mountain in the Home quadrangle. The former divide, except for the above remnants, was destroyed by headward erosion and stream capture by the South Platte River and its tributaries.

Transverse profiles show that the present divide is west of and lower than high remnants of the former divide. Three of four Front Range peaks over 14,000 feet lie east of the present divide. Six peaks between 13,000 and 14,000 feet that lie east of the present divide are higher than the present divide immediately west of them.

Major folds and thrust faults adjacent to the Front Range trend northwest. Larger folds, such as Medicine Bow Range, Rampart Range, and Red Creek Arch, project along parallel northwest-trending lines which coincide with the highest parts of the Front Range. The largest single fold trends northwest from Red Creek Arch through Pikes Peak, Tarryall Mountains, Mt. Evans, Grays-Torreys, and Byers Peak to a thrusted anticline near Troublesome.

Physiographic and structural evidence suggests that, in early Tertiary time, the Front Range consisted of a series of en echelon, northwest-trending mountain ridges compounded into a single north-trending mountain mass.

CANJILON HILL, A CAULDRON SINK NEAR BERNALILLO, NEW MEXICO

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1908 Silver S. E., Albuquerque, N. M.

Canjilon Hill is located on the west side of the Rio Grande, north-northwest of Bernalillo. Exposed on the hill is a local unit of fanglomerate which forms an elongate saucer-shaped body 4100 feet long, 2200 feet wide, and 280 to 500 feet thick. Unlike the surrounding Santa Fe beds these strata contain abundant large angular basalt fragments. Structural and sedimentological evidence suggests that the basaltic fanglomerate was deposited in a collapse depression initiated on the Pleistocene (?)

Ortiz surface. The cause of collapse is uncertain but was probably due to withdrawal of support in an underlying magma chamber. The basalt fragments in the fanglomerate may have been derived in either or both of two ways: (1) erosion of surrounding basalt flows; (2) explosion of basaltic pyroclastic material. Continued subsidence during deposition of the fanglomerate is suggested by unconformities and inward dips exceeding the angle of repose. Normal faults along which subsidence occurred are exposed along the periphery of the hill. The total subsidence was at least 300 feet. A later period of igneous activity is represented by a large funnel-shaped basaltic extrusive vent associated with what may be a cone sheet and numerous dikes cutting the fanglomerate.

STRUCTURE AND PARAGENESIS OF FLUORSPAR DEPOSITS

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Structural and paragenetic studies of numerous fluorspar deposits in the Western United States, especially in Colorado and New Mexico, lead to the following generalizations:

(1) Certain intricately layered deposits, many complex breccia deposits, and many deposits containing "boxwork" fluorite were formed in open spaces by processes of alternating solution and deposition or redeposition of both vein minerals and wall-rock minerals.

(2) Some deposits were formed by wall-rock replacement or by a combination of replacement and open-space filling.

(3) Complex control of environment of the time of fluorite mineralization is indicated by rapid vertical and lateral changes in structure, mineralogy, and texture.

(4) The temperature range of fluorite deposition is probably much greater than that of most types of ore deposits.

TERTIARY OIL AND GAS FIELDS IN UTAH AND COLORADO

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Significant amounts of nonmarine hydrocarbons are being produced in the intermontane region. Up to January 1, 1956, 19 fields, totaling 161 wells, in the Uinta, Piceance Creek, and Sand Wash basins of Utah and Colorado had produced commercial quantities of oil or gas from continental Tertiary sediments. Approximately 71 produce oil, 85 gas, and 5 contain both. Many gas wells are shut in because of inadequate marketing facilites. One field, Hiawatha, extends into Wyoming.

The following formations of Paleocene and/or Eocene age contain the productive intervals: Fort Union, Wasatch, Green River, and Uinta. The primary environments of deposition were lacustrine and fluvial, with minor deltaic and paludal phases. Stratigraphically these formations are complex and display, in very short distances, intricate lateral and vertical facies changes which make correlation difficult. Many unusual lithologic types and rare minerals are present in lacustrine facies.

Lenticular sandstone beds with interstitial porosity, fractured shale and sandstone beds, and ostracodal limestones are the predominant reservoirs.

Information on formation water salinities is limited, but none exceeding 33,000 ppm are known.

Closed anticlines and domes, anticlinal noses, fault closures, and stratigraphic traps localize the accumulations. Structure is probably not nearly so important as the development of source beds in favorable reservoir locales. Configuration of the structures changes with depth in many cases.

Oil gravity ranges from 23° to 42° A.P.I. and pour point from 65° to 100° F. Wax content is often unusually high. Three fields—Powder Wash, Hiawatha, and Red Wash-Walker Hollow—contain 72 per cent of the commerical wells.

The source is believed to be indigenous to these continental formations, and probably lacustrine facies were largely responsible.

GEOLOGIC SETTING OF SUMMITVILLE MINING DISTRICT, COLORADO

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The Summitville mining district in the San Juan Mountains of Colorado has produced gold with subordinate values in silver, copper, and lead from replacement veins and pipelike ore bodies in the Fisher quartz latite (Miocene).

The Fisher quartz latite overlies a thick accumulation of dark flows of the Conejos quartz latite and consists of an older and a younger member, separated by an irregular erosion surface. The older member comprises volcanic domes and flows of dacitic and latitic composition, with pyroclastic materials; the younger member consists of rhyolitic flows.

Solfataric wall-rock alteration and mineralization are closely dated as following eruption of the older member of the Fisher and preceding extrusion of the rhyolite of the younger member of the Fisher quartz latite. The ore bodies follow intersecting fractures within a large volcanic dome and are believed to be localized above one margin of the underlying plugged conduit of the dome.

UNUSUAL FOLDS IN MOENKOPI FORMATION AROUND FISHER VALLEY, UTAH

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The center of Fisher Valley, Utah, is underlain by a large intrusive mass of salt, gypsum, and clastic sedimentary rocks derived from the Paradox member of the Hermosa formation of Pennsylvanian age. This intrusive salt mass was emplaced and exposed at the surface in pre-Triassic time. The Moenkopi formation of Early and Middle (?) Triassic age rests locally on the intrusive mass with sedimentary contact. Movement of the salt intrusion continued, however, until post-Moenkopi time, as is shown by local pinching out of the Moenkopi formation on the flanks of the intrusion. A series of 13 small anticlines radiates from the intrusive salt mass. The anticlines have wave lengths up to 200 yards and amplitudes up to about 200 feet. One anticline has an observed axial length of about half a mile. The anticlines are unusual and possibly unique because they are confined to the Moenkopi formation. The beds of the Moenkopi on the crests of the anticlines are truncated by the overlying Chinle formation. The Cutler formation, unconformably beneath the Moenkopi formation around the salt intrusion, is undeformed beneath the anticlines where the top of the Cutler rises in the anticlinal crests.

It is suggested that the anticlines originated by lateral sliding of the Moenkopi formation over hills on the pre-Moenkopi surface. Movement of the salt intrusion during and after the deposition of the Moenkopi probably initiated the sliding.

RELATION OF GROUND WATER TO STREAM FLOW IN NEW MEXICO IN LATE CENOZOIC TIME

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By the end of the Pliocene, most of New Mexico had been covered by thick sediments that filled deep grabens in north-central and southwestern New Mexico, or covered extensive platform areas such as eastern, west-central, and northwestern New Mexico.

Widespread orogenic movements occurred near the end of Pliocene time. Many grabens and horsts were accentuated or created, and a new cycle of sedimentation eroded and redeposited large amounts of the Pliocene and older sediments in contiguous closed drainage basins, alluviated valleys, and piedmont plains that covered most of New Mexico. Ancient playa lake basins and the ancestral San Juan, Gila, Rio Grande, Canadian, and upper Pecos rivers probably formed at this time along axes of sedimentation that were controlled by the structure and lithology. Ground water moved toward the playa lakes and generally downstream subparallel to the master streams, approximately in the directions of present ground-water movement, except in the lower Pecos River valley.

Surface water in New Mexico now discharges into the Colorado, Rio Grande, and Lower Mississippi

drainage systems, and into 12 closed surface basins. Ground water in the through drainage basins generally discharges to the respective principal stream valleys. Most of the ground water from five of the closed surface basins discharges into adjacent tributaries of the major through drainage systems. Ground water is discharged to the atmosphere within New Mexico in the Playas and Estancia valleys, into a closed basin in Texas from the Sacramento River basin, and into Mexico from the Mimbres, Hachita, Wamel, and San Luis basins in southwestern New Mexico.

CENOZOIC VOLCANIC ROCKS AND STRUCTURE OF THE NORTHERN MARKAGUNT PLATEAU, UTAH

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From the Pink Cliffs at the south rim of the Markagunt Plateau, a volcanic terrain of more than 500 square miles extends northward until it merges with the volcanic Tushar Plateau of central Utah. Although the Tushar has been studied extensively, in connection with its deposits of alunite and uranium ores, the geology of the northern Markagunt is as little known today as it was 75 years ago, when C. E. Dutton published his classic report on the geology of the High Plateaus of Utah.

Recent studies of the Markagunt Plateau have shown that as much as 10,000 feet of bedded andesitic pyroclastics, rhyolitic welded tuff, and basaltic agglomerate conformably overlie the Pink Cliffs "Wasatch". Several dolerite dike swarms appear to represent feeders for the widespread agglomerate which seems appropriately designated as "plateau breccia", by analogy with the more familiar plateau lavas and ignimbrites associated with fissure eruptions. No direct means of dating the volcanic sequence is available, but regional relationships and probable correlation with the Bullion Canyon volcanics of the Marysvale, Utah, area suggest an Eocene-Oligocene age.

During and after deposition of the youngest part of the volcanic sequence, the northern and western parts of the Markagunt Plateau block were arched broadly and broken by high-angle faults, the most important consequence of which is the Bear Valley graben that averages 2 miles in width and extends north-northeastward, 35 miles from Cedar Breaks National Monument to Utah State Highway 20.

PERMO-PENNSYLVANIAN STRATIGRAPHY OF THE BUFORD AREA, RIO BLANCO COUNTY, COLORADO

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The Desmoinesian Minturn formation, stratigraphically the lowest outcropping formation in the Buford area, consists of gray sandstones and siltstones in its lower part and grayish-red to reddish-brown sandstones above, with interbedded black shale and gray fossiliferous limestone. One limestone member is believed to be in part a reef complex. Gypsum is interbedded with the clastics and limestones; spectacular solution breccias and flow structures have developed where the gypsum has been dissolved. The Jacque Mountain limestone separates the Minturn and Maroon formations. From southwest to northeast: (1) the Jacque Mountain limestone pinches out into gypsum, (2) the gypsum thickens at the horizon of the Jacque Mountain limestone, and (3) the red sandstones of the Maroon formation immediately above the Jacque Mountain limestone change laterally to yellowish-gray sandstones and siltstones.

The Maroon formation (upper Pennsylvanian and lower Permian?) consists of brownish-red and moderate red, well-sorted arkoses and quartzose sandstones. A median arkose separates the Schoolhouse Tonque of the Weber formation (lower and middle Permian?) into an upper and lower unit. A coarse-grained sandstone caps the tonque and is believed to thicken and coarsen to the southeast. The State Bridge formation is Guadalupian in its lower part where it contains the South Canyon Creek dolomite member. The Permian-Triassic boundary lies within the red siltstones and gray sandstones of the State Bridge.

GEOLOGY OF URANIUM IN THE TERTIARY BASINS OF WYOMING AND THE NORTHERN GREAT PLAINS

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Commercial uranium deposits in the Tertiary basins of Wyoming and the northern Great Plains occur in areas of thick Tertiary sedimentary rocks, commonly remote from metallic vein deposits. Concentrations of uranium in sandstone, limestone, and coal are thought to be secondarily derived from mineralizing solutions, as suggested by the crosscutting relations between uranium minerals and primary sedimentary structure. Structure and permeability appear to control the distribution of uranium. Lithologic variations determine the physical and chemical environment of deposition. Any apparent spatial relation between the distribution of uranium and petroleum is probably fortuitous. Radioactive disequilibrium and the occurrence of uranium minerals in caliche and pediment gravel testify to the mobility and recent deposition of some of the uranium. Deposition of uranium probably takes place in a moderate- to low-temperature environment.

Three hypotheses for the source of the uranium are considered: (1) thermal solutions genetically related to magmatic intrusion, (2) leaching and concentration of disseminated uranium in volcanic ash, and (3) lateral secretion and concentration of disseminated uranium in sedimentary rocks laterally equivalent to the host formation. All three may be operative in different areas. The following classification for the deposits, as based on the environment of deposition, is suggested: surficial, vadose, hydrodynamic.

FROSTING OF QUARTZ GRAINS BECAUSE OF SOLUTION ETCHING

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Clastic quartz grains in contact with calcite or dolomite in sedimentary rocks commonly have frosted surfaces that resemble those on sand grains in eolian deposits. In studies of insoluble residues misinterpretation of such frosting leads to erroneous conclusions regarding genesis.

Thin-section studies indicate that the frosting results from solution etching at the contact between the carbonates and quartz and that partial to complete replacement of quartz by carbonates is common and widespread in sedimentary rocks.

CLAY MINERALS IN THE CRETACEOUS ROCKS OF THE TOHACHI QUADRANGLE, NEW MEXICO*

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A detailed investigation of the clay minerals in two measured sections of the Cretaceous rocks of the Tohachi quadrangle, New Mexico, indicates that these minerals may be helpful in the differentiation and correlation of Cretaceous rocks over a broad area. Kaolinite, illite, montmorillonite, halloysite, pyrophyllite, and mixed-layer clay have been identified. The distribution and relative percentages of these minerals is the same in both sections. On the basis of clay mineralogy, the two measured sections are divided into 14 units. Within the limits of this study (3 miles) these clay units closely coincide with changes in lithology; with wider limits, this coincidence probably would not persist. Five occurrences of montmorillonite were discovered in each of the two measured sections. Montmorillonite should be most abundant in sediments that accumulated during periods of volcanism; it most commonly develops from the alteration of volcanic ash. Hence, the five occurrences in the measured sections are interpreted as representing time intervals during which volcanism occurred. It should be possible to recognize these intervals elsewhere in the San Juan basin, regardless of changes in lithology. Kaolinite is present in all the samples. Inasmuch as kaolinite is typically the product of weathering in an acid environment, its persistence even in the deep-water marine sediments suggests rapid accumulation of all these Cretaceous sediments.

* Publication authorized by the Director, New Mexico Bureau of Mines and Mineral Resources.

GEOMORPHIC EFFECTS OF LATE PLEISTOCENE CLIMATIC CHANGES IN SOUTHEASTERN IDAHO AND NORTHERN UTAH

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Dry Valley, in the Pruess Range of southeastern Idaho, shows topographic forms apparently shaped by a much larger overland runoff than has occurred in recent geologic time. A thick layer of coarse alluvium, graded in long wash slopes from the valley sides, occupies the valley bottom. Outcrops of the phosphatic shale member of the Phosphoria formation appear to have been affected particularly by solifluction and to have provided large quantities of congeliturbate—mud mixed with blocks of chert from the overlying Rex member—which moved down the valley slopes. These features are thought to be the result of the Wisconsin periglacial climate.

In the canyons of the Bear River Range east of Logan, Utah, valley-bottom flats, graded to the Provo shore line of Lake Bonneville, are well developed. On these flats comparatively large alluvial fans have been deposited beneath gullies tributary to the canyons. The fans coalesce distally and appear to have grown without interference from a perennial stream such as now occupies the canyon. Along the base of the Wasatch Range near Willard, Utah, the growth of alluvial fans, subsequent to the last recession of Lake Bonneville, but prior to post-lake movement on the Wasatch fault, has been partly by mud-rock flows. More recent growth appears to have been by better-sorted alluvium.

Fan growth is credited to the altithermal age, 7,500–4,500 B. P., and to truncation and regrading to the more humid medithermal age which has followed.

OCCURRENCE OF *TEMPSKYA MINOR* IN STRATA OF ALBIAN AGE IN SOUTHWESTERN NEW MEXICO

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For many years it has been known that a thick Lower Cretaceous sequence is present in parts of southwestern New Mexico and southeastern Arizona. Recent work in the Big Hatchet Mountains, Hidalgo County, New Mexico, has resulted in the discovery in the upper part of the sequence of the enigmatic fossil *Tempskya minor* Read and Brown in close association with marine invertebrates that indicate an Albian age for the enclosing rocks.

Approximately 10,000 feet of Cretaceous rocks is exposed in the Big Hatchet Mountains, of which the lower half is marine limestone and shale beds of Glen Rose age, and the upper half is interbedded continental quartz sandstone and shale beds. Thin marine limestone interbeds appear near the top of the clastic interval, and *T. minor* is found in this upper part about 4250 feet above the base of the unit.

T. minor is the most common of the North American species of the genus and is known from numerous localities in Lower Cretaceous rocks in the western United States. It has been reported from the Wayan formation in Idaho, the Aspen and Thermopolis formations in Wyoming, the Dakota sandstone in Utah, and the Overton fanglomerate in Nevada. It has not, however, been previously reported from Comanchean strata. The association of *T. minor* in the Big Hatchet Mountains with marine fossils that are Albain in age is of some interest. Not only does it extend the geographic spread of the genus *Tempskya* but it also supports the opinion that the several species may be guide fossils to the Albian.

ABSTRACTS OF PAPERS PRESENTED AT THE SEVENTH ALASKAN SCIENCE CONFERENCE (AAAS), JUNEAU, ALASKA, SEPTEMBER 27–30, 1956

HYDROGEN ION AND SOLUBLE HEAVY-METAL DISTRIBUTION OF SOIL HORIZONS OVER THE CLEARY HILL GOLD VEINS, ALASKA

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Soil samples from the principal soil horizons, Cleary Hill mine, Fairbanks district, Alaska, have been analyzed by colorimetric methods for pH and soluble heavy metals. Six hundred and sixty samples were collected from 165 auger holes arranged in eight lines 200 feet apart and perpendicular to the general trend of the veins. Mapping included underground workings, surface relief, and variations in soil horizons.

The distribution of hydrogen ions at the Cleary Hill mine is related principally to the humic-acid content of the soil horizon. Minor hydrogen-ion variations occur within each soil horizon. There may be a correlation between pH and some portions of the gold veins, but the colorimetric method was not accurate enough for reliable correlation.

Heavy soluble metals, at the Cleary Hill mine, are accumulated in the Aoo and Ao horizons; they are brought to the surface through the roots of plants year after year. As the organic mat accumulated over hundreds of years, there was a higher content of soluble metals in these two horizons over the A, B, and C horizons.

The distribution of the soluble heavy metals is variable within every soil horizon. In the upper (Aoo and Ao) soil horizons this variation is pronounced enough to provide a rather reliable correlation between the soluble heavy-metal content of the soil horizon and the gold veins.

The principal reason for this is that the gold veins carry minor amounts of lead, zinc, and antimony.

TESTS OF GEOPHYSICAL PROSPECTING TECHNIQUES IN AREAS OF SPORADIC PERMAFROST IN INTERIOR ALASKA

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In 1952 the U. S. Geological Survey, at the request of the Corps of Engineers, tested the applicability of resistivity and seismic-refraction techniques in prospecting for ground water near Fairbanks, Big Delta, and Tok, Alaska. The seismic-refraction method proved to be an excellent method of detecting permafrost and mapping its upper surface, but little success was attained in mapping the bottom of the permafrost or the upper surface of the bedrock. Resistivity techniques were a fairly reliable indicator of the presence of permafrost and provided an estimate of its thickness, but the lack of adequate interpretation curves and the effects of severe lateral variations in surface resistivity limited the accuracy of the depth measurements.

THERMAL DISTURBANCE IN PERMAFROST RESULTING FROM ROAD CONSTRUCTION

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In permafrost areas of Alaska both paved and unpaved roads often disintegrate during the late summer of the second season after construction has started. Some insight into this phenomenon is afforded by studies made of the thermal disturbance beneath old and new roads and/or gravel fills in the vicinities of Glennallen, Umiat, and Barrow, Alaska, during the last 4 years. The disintegration of the roads is related to a transient increase in the amplitude of seasonal ground-temperature oscillations in the active layer and in the underlying permafrost, following the disturbance of the ground surface. There is usually better drainage in the roadways, and the better drainage plus the temper-

ature effect result in a greater depth of thaw. The greater thaw causes the melting of ice inclusions in the permafrost and results in differential settlement at the surface. The depth of gravel fill does not materially affect the mean annual ground temperatures beneath the road.

SEISMIC MEASUREMENTS IN PERMAFROST AREAS OF INTERIOR ALASKA

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In 1953 the Air Force Cambridge Research Center made extensive seismic measurements near Fairbanks. Refraction profiles mapped the upper surface of the permafrost successfully. Dispersion of flexural waves was detected, but lack of an adequate theoretical model prevented their use for thickness measurements. Furthermore, the long distances required for dispersion measurements deprive the technique of sufficient resolution for most prospecting applications.

SOME ASPECTS OF QUARTERMASTER GEOGRAPHIC AND CLIMATIC RESEARCH IN COLD ENVIRONMENTS

Fernand de Percin
QM R&D Command, Natick, Mass.

Quartermaster Corps geographic and climatic research in cold environments began during the early stages of World War II when a small group of geographers and climatologists were gathered together to form the Cold Climate Unit of the Office of the Quartermaster General. In 1947, an Arctic Project was formally established, and in 1954 this became Cold Environments.

The current research program in cold environments includes the following work phases: (1) the preparation of Environmental Handbooks for Department of the Army Test Sites and other locations where tests are conducted frequently, including Big Delta and Whittier, Alaska, Fort Churchill, Canada, Devils Lake, N.D., Mt. Washington, N.H., Ft. Lee, Virginia, and Natick, Mass., designed to provide pertinent information, especially climatic, concerning environmental conditions at each location; (2) at the request of the Corps of Engineers, studies of climatic analogs for cold-weather test sites, which compare the climates of Big Delta, Alaska, Fort Churchill, Canada, and Devils Lake, North Dakota, with the climates of cold regions in Eurasia and North America; (3) microclimatic studies at cold-weather test sites and other areas to determine local variations in climate in order to provide accurate information for those who plan and conduct tests at these installations, and to gain additional knowledge of the actual field conditions under which troops must operate and equipment must function; (4) studies of the frequency, duration, and distribution of climatic elements, both singly, as for temperature, and for combination of weather elements, as for those defining cold-wet or cold-dry conditions. These studies are required to provide information necessary for the proper development, issue, and use of items of clothing and equipment.

RÉSUMÉ OF THE GEOLOGY AND GEOMORPHOLOGY OF THE ISLANDS OF THE BERING SEA

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The rapid advance in knowledge of the geology and geography of Alaska has largely by-passed the isolated islands of the Bering Sea. Scattered scientific investigations, for the most part, have been of limited duration and for specific objectives. This paper brings together some of the results of these investigations.

The islands lie within the shelflike area of the shallow waters of the northeastern part of the Bering Sea. They range in size from Sledge Island, 1½ miles in length, to St. Lawrence Island, 110 miles long and covering an area half again the size of Rhode Island.

With the exception of St. Lawrence and Nunivak islands, which contain several large masses of sedimentary rocks, the islands are composed predominantly of volcanic rocks of varying age. On St.

Lawrence and the Pribilof Islands the volcanic activity is believed to have continued into Pleistocene and Recent time.

Economic minerals are scarce. Coal occurs on St. Lawrence and Nelson islands but not in amounts sufficient for more than local use by the natives. Pyrite, galena, sphalerite, and molybdenite are found on St. Lawrence Island, but no economically valuable deposits have been reported. Amber fragments are occasionally picked up on the beaches of Nelson Island, and in earlier days red and yellow oxides, suitable for decorative pigments, were used as items of barter among the natives.

The future economic significance of the geology of these islands may be expected to lie not in any major mineral deposits, but rather in their striking geomorphologic features, which will eventually become known as tourist attractions and draw many visitors to the islands. The beautifully formed cuspate beaches of St. Lawrence Island, the wave-lashed spires and needles of Pinnacle Rock, the cinder cones and jagged lava flows of St. Lawrence and the Pribilofs, and the 1000-foot cliffs of Cape Vancouver are but a few of these features.

Geologists and geomorphologists through their understanding and interpretation of these features will constantly stimulate greater public interest in them.

POSSIBLE ORIGIN OF THE PLACER GOLD DEPOSITS OF THE NELCHINA AREA, ALASKA

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The Nelchina area, Alaska, comprising the southeast foothills of the Talkeetna Mountains, has yielded a small production of placer gold since 1911, principally from the gravels of Albert Creek, a minor stream in the drainage of the Little Nelchina River. The gold occurs in both high and low valleys throughout most of the area. It is here suggested that continental gravels of Eocene age, inferred to have overlain most of the area in late geologic time, contained concentrations of placer gold which were reworked during late Pleistocene and Recent time to form the present placers.

The area is underlain by slightly altered volcanic rocks and unaltered marine sedimentary rocks of Jurassic and Cretaceous age, upon which a subaerial erosion surface of low relief was formed during Eocene time. Several hundred feet of gravels of Eocene age overlies this surface in the eastern part of the area. Westward the gravels thin, are restricted to channels, and are buried by basaltic volcanic rocks of Eocene age.

Neither veins nor intrusive rocks of types that elsewhere carry gold are known from the Nelchina area. Gold has not been reported from valleys cut solely in the volcanic rocks of Eocene age, and the only older rock whose extent in late Cenozoic time corresponds to the widespread occurrence of gold is the gravel of Eocene age.

The distribution of the placers indicates that glacial till or outwash from outside the area was not a significant source of the gold. For example, placer gold was found on upper Mazuma Creek, downstream from an outcrop area of the gravels of Eocene age. The Mazuma Creek valley is cut mainly in the overlying volcanic rocks, and the sharp arêtes and horns that surround it indicate that it was not overridden by ice from other areas after the present drainage was formed by local cirque glaciers.

The pieces of gold are prevailingly smooth and flattened, indicating longer water transport from the place they were hydrothermally deposited than could have occurred in the small streams in which they are found. On Albert Creek the pieces of gold range from dust to nuggets occasionally as heavy as half an ounce Troy, but are smooth and flattened, rarely contain adherent gangue, and are of very uniform fineness. These characteristics are consistent with an origin in the Eocene gravels and antithetical to an origin in local bedrock or in the glacial drift.

EXPERIMENTS IN DRIVE SAMPLING OF FROZEN GROUND

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Design of structural foundations for permafrost regions requires knowledge of subsurface soil conditions. Subsurface explorations at proposed sites are essential to ascertain soil profiles and obtain

undisturbed soil samples. The most commonly employed methods for subsurface soil explorations consist of test pits and core borings using rotary-drilling equipment. Both methods have distinct disadvantages when applied to frozen ground. Subsurface explorations have been made at the Permafrost Research Area of the Corps of Engineers, U. S. Army, about 2½ miles northeast of Fairbanks, Alaska, in connection with research studies for the development of design criteria for construction on frozen ground. A third method of drive-sampling procedures was used effectively for sampling fine-grained frozen soils. A drive sampler constructed from 3-inch I.D. standard steel pipe and adapted to an ordinary well-drilling machine or churn drill was highly successful for drive sampling to considerable depth in frozen-silt soil. Another drive-sampling arrangement consisting of a drive hammer supported from a tripod and powered by the "cathead" of a rotary-drilling machine also proved effective in frozen fine-grained soils. Other drive-sampling arrangements using both power-driven equipment and manual-driving procedures show considerable promise. Drive-sampling experiments have been conducted using several types of manufactured drive samplers and several samplers developed in the field. Many of the manufactured samplers are designed for driving in thawed soils and are consequently ineffective in frozen soil. Drive sampling in frozen soil using manual procedures is difficult at depths exceeding 10 feet because of the difficulty of manual withdrawal of the sampler following each drive. However, other methods of sampler withdrawal may be used, such as hydraulic jacks, winches, or block and tackle. More experimentation is needed for the development of equipment and techniques for sampling frozen subsurface soils. Experiments will continue at the Permafrost Research Area in connection with other research studies for construction on frozen ground.

METHOD OF ESTIMATING THE THERMAL INFLUENCE OF HEATED BUILDINGS ON PERMAFROST

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A formal solution has been obtained for the problem of heat conduction in a homogeneous semi-infinite medium in which the temperature at the surface varies sinusoidally with time and the mean temperature and amplitude of the variation are different within and outside an arbitrarily shaped region of the surface. The amplitude and mean temperature can be treated as functions of position within the arbitrary surface region. For certain simple surface regions the results can be expressed in terms of tabulated functions. Numerical results for the general case can be obtained by simple graphical procedures.

The results can be applied to the study of ground temperatures disturbed by bodies of water or by engineering surface modifications such as those produced by erecting a heated building. The primary application of such studies is in high-latitude regions where much of the undisturbed ground is perennially frozen. In such areas, a method of predicting the extent of thawing induced by various modifications of the temperature of the ground surface is important in problems of engineering design and logistics.

SIGNIFICANCE OF THE ANOMALOUS ADVANCES OF ALASKAN COASTAL GLACIERS

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A regional assessment is given of the extraordinary glacier advances in Southeastern Alaska since 1900. Special reference is made to the 16 glaciers of the Taku-Llewellyn system on the Juneau Icefield, where detailed regime studies have been conducted since 1946. Fourteen of these are now retreating although 10 experienced a noteworthy resurgence between 1890 and 1925 in a late phase of the Alaskan "Little Ice Age." Only the Taku and its distributary tongue, Hole-in-Wall Glacier, have continued to advance and have pushed out nearly 4 miles since 1895. This anomalous pattern results from a significant upward shift in the level of maximum solid precipitation over the Coast Range between 1885 and 1945, coincident with pronounced regional warming in this interval. The geophysical effects of a strong reversal in the regional winter-temperature trend since 1944 is analyzed.

Orographical factors are also considered as they affect the minor variations of termini at lower levels. The probable future behavior of these ice masses is discussed, and a method being instituted for forecasting fluctuations of the trunk glaciers in Coastal Alaska is outlined.

FIELD RECOVERY OF REAGENTS FOR GEOCHEMICAL PROSPECTING

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Of the reagents used for geochemical prospecting, organic solvents are required in greatest quantities. Upon use, these solvents become contaminated with metals or oxidized indicator and are not satisfactory for further use. At present, the used solvents are discarded, except carbon tetrachloride which is recovered in the laboratory by distillation. Carbon tetrachloride is not inflammable, but most other solvents used in geochemical prospecting are inflammable, and special care must be taken if the solvents are to be recovered by distillation.

A method for recovery has been developed on the basis of the adsorption principle by using activated charcoal or charcoal prepared in the field to recover, without the use of fire, all impure organic solvents. The procedure involves two simple steps: (1) the removal of impurities by adsorption, and (2) the removal of the adsorbent.

The indicator, dithizone, and a solvent can be recovered by dilute acid or base. The oxidized indicator can be recovered by reduction in the presence of a readily available catalyst, iron filings or powder.

FROST ACTION ON PILING NEAR FAIRBANKS, ALASKA

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Frost action annually causes vertical displacement of bridge piling on many Alaska Railroad bridges in Goldstream valley near Fairbanks, Alaska. The necessity of restoring track elevation and periodically redriving displaced wooden piles results in great maintenance expense.

Important factors favoring intense frost action in central Alaska are long periods of intense cold, widespread deposits of fine-grained sediment (mostly silt), and high moisture content of sediment caused in part by shallow permafrost which restricts drainage. Depth to permafrost is 2–3 feet in silt of the Goldstream valley except in drainageways where it may be 15–20 feet deep. The active layer is generally 3–4 feet thick except where permafrost is closer than 3–4 feet to the surface.

Piling firmly anchored in permafrost is rarely displaced by seasonal frost action. The pile, to resist frost heave, should penetrate permafrost to a depth of at least twice the thickness of the active layer. Investigations at three Alaska Railroad bridges indicate that many of the wooden piles are not adequately anchored in permafrost.

The temperature of permafrost in the area is 31°–32°F., and steam thawing of holes prior to pile emplacement in permafrost introduces heat that retards refreezing of the ground around the pile. Delay in refreezing permits seasonal frost action to displace the piling.

GROUND-WATER SUPPLIES IN THE JUNEAU AREA, ALASKA

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Ground water for domestic supplies is available at relatively shallow depth in the Juneau area, Alaska. Water-bearing sands or gravels are found overlying, within, or beneath the glacial till (locally called hardpan or blue clay), which is the predominant surficial material along both sides of Gastineau Channel. Near the mouths of the larger streams that disgorge from the mountains, thick sand and gravel deposits were formed which contain potable ground water. Where fractured extensively the bedrock supplies a limited amount of water; elsewhere, it supplies essentially none. The ground water is recharged by precipitation and streamflow which percolate into the ground along the mountain slopes.

ENGINEERING AND PERMAFROST STUDY IN THE GLENNALLEN AREA, ALASKA: PROGRESS REPORT

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The installation of recording devices for the co-operative engineering Permafrost Studies in the Glennallen area of Alaska is practically complete.

The second phase of the long-range program, the routine collection of field data, is progressing according to the original plan. Some of the data are being reduced, checked, and plotted in order to attempt to correlate the results of the roadway studies with those of the larger Arctic Ice and Permafrost Project, of which this is a part.

The preliminary thermal data have been applied to the problem of the annual spring break-up of highways, and to the problem of differential settlement of the large apartment house at Glennallen.

Subsurface thermal data are being collected from 27 thermistor cables in and near the roadway section, 6 thermistor cables under an apartment house, 2 thermistor cables in deep wells, and 2 thermistor cables in undisturbed areas. Six continuous thermographs have been installed in or adjacent to the study sections. In addition, 10 Fiberglas soil-moisture units have been installed in the main study section at Mile 130 of the Richardson Highway.

ABSTRACTS OF PAPERS SUBMITTED FOR MEETING IN NEW YORK N. Y., DECEMBER 26–30, 1956 (SECTION E, AAAS)

ISOTOPIC CHRONOMETERS FOR THE PLEISTOCENE AND RECENT

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Dating by istopes other than C^{14} for Pleistocene events is discussed. The history of ionium dating is reviewed, and new work on beryllium^{10} is described. Much further work remains on these isotopes before they can be safely used for dating purposes. Other possible species for dating in this region of time are also discussed.

CLASTIC LIMESTONE CALCARENITES AND PRECIPITATED CALCARENITES

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An exaggerated role has been ascribed to the formation of limestones by the breakdown of pre-existing limestones. Such limestones have commonly been referred to in the literature as clastic limestones, and they have been regarded as a major limestone type comparable with skeletal (or bioclastic of some authors) limestones and precipitated limestones. Precipitated granular limestones may grade from calcilutites to calcirudites, and their grains may exhibit either oriented (*e.g.*, oölitic) or disorganized (mosaic) microstructure.

Precipitated calcarenites are forming under very shallow marine conditions at the present time. Similar conditions of deposition are inferred for ancient deposits.

Many, in fact probably most, of the granular limestones hitherto commonly referred to as clastic are now regarded as precipitated.

Criteria for recognizing varying types of calcarenite are discussed.

CURRENT TECHNIQUES AND PROBLEMS IN RADIOCARBON DATING

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The physical principles and assumptions on which the radiocarbon dating is based are described. The limitation of the method will be reviewed including effects due to fractionation, contamination, and short-term variations in the cosmic-ray flux. Present techniques allow contemporary materials to be measured with a precision of within ½ per cent. The sensitivity is such that samples as old as 50,000 years can be dated. Extension of the time range of the C-14 method requires further advances in instrumentation, pre-enrichment techniques, and experimentation to establish contamination levels in ancient materials used for dating.

STRATIGRAPHIC RELATIONSHIPS IN NORTHERN VERMONT AND SOUTHERN QUEBEC

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Major structures in northern Vermont and southern Quebec plunge north, and rather unintelligible Cambrian and Ordovician crystalline cores of anticlines extensively exposed in Vermont give way northward to structurally higher and lithologically distinct strata of Cambrian to Devonian age. The stratigraphy of neighboring Quebec is therefore better understood than that to the south and is a key to stratigraphic correlation in Vermont. The most uncertain stratigraphic relationships are in the Green Mountain-Sutton Mountain anticlinorium and in adjacent synclinoria, though a near synonymy of the Camels Hump group of Vermont with the Sutton of Quebec, the Ottauquechee and Stowe formations of Vermont with the Mansonville of Quebec, and the Moretown formation of Vermont with the Beauceville of Quebec is now clear east of the Green Mountain-Sutton Mountain

axis. The Green Mountain-Sutton Mountain anticlinorium and the Chaudiere synclinorium to the east are difficult to bridge in east-west stratigraphic correlation because the most distinctive stratigraphic units have been eroded from the anticlinorial axis or are at depth in the synclinorium. The distinctive lithologic features of the Moretown formation are repeated in an anticlinorial belt east of the Chaudiere synclinorium, and a correlation is implied. The Ottauquechee formation is tentatively correlated with lithologically similar rocks west of the Green Mountains. Proof of such a correlation of the Ottauquechee, and of the other formations of the east limb of the Green Mountain-Sutton Mountain anticlinorium in Vermont, must come from Quebec where the anticlinorium plunges northward, and critical units that are eroded from the anticlinorium in Vermont may be traced across its axis.

GEOLOGY OF THE DANBURY AND BETHEL QUADRANGLES, CONNECTICUT

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Units of the Precambrian Highlands underlie the northwestern portion of the Danbury quadrangle; they are (1) gneissic granite and trondhjemite, (2) hornblende gneiss and amphibolite, and (3) Danbury augen granite. The Highlands fault marks the contact between this complex and the New York City group, which lies to the east and south. The formations that constitute the New York City group are (1) Fordham gneiss, (2) Inwood marble, and (3) Manhattan formation; they extend from the western edge of the Bethel quadrangle eastward and then swing northward through the length of the Danbury quadrangle. The continuity of these units with the type localities to the west in New York seems well established; their extension to the north, however, is uncertain. To the east and south of the New York City group is the Hartland formation. The Hartland formation is host to several plutons of the Brookfield plutonic series. The New York City group, the Hartland formation, and the Brookfield plutonic series are all invaded by younger granites.

RUBIDIUM-STRONTIUM AGES OF GLAUCONITE

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The ages of 17 glauconite samples have been measured utilizing the Rb/Sr method of age determination. The concentration of rubidium, common strontium, and radiogenic strontium was determined using the stable isotopic dilution method of analysis. In the case of 14 of the glauconites analyzed, common strontium extracted from the glauconites was analyzed isotopically, and the relative abundances of the four strontium isotopes were determined. This was done in addition to the strontium isotope dilution analyses and allowed a significantly more accurate determination of radiogenic strontium. In all but one case the sample analyses were obtained on sediments well dated paleontologically. Six of the samples were from Cambrian strata and gave ages from 392 to 584 million years. Three Ordovician glauconites gave ages ranging from 375 to 471 million years. A lower Devonian sample resulted in an age of 321 million years; three Upper Cretaceous-Lower Eocene glauconites gave ages of 55, 59, and 71 million years. A recent glauconite from the Atlantic Ocean off Georges Bank gave an age of 0. The ages obtained were compared by absolute age determinations made by other workers on material thought to be well dated on the basis of geologic evidence and were compared with the Holmes B time scale.

GROUND WATER IN NORTH-CENTRAL CONNECTICUT

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The north-central Connecticut of this report is an area of about 640 square miles, extending from the Connecticut-Massachusetts State line south to Middletown. It is underlain by unconsolidated deposits of Pleistocene and Recent age, which mantle an erosional surface formed on consolidated rocks of pre-Triassic and Triassic age.

The unconsolidated deposits include ground moraine and glaciofluvial, glaciolacustrine, and eolian deposits. The ground moraine (till) occurs throughout most of the area but yields only small quantities of water. The glaciofluvial deposits comprise sand, silt, and some gravel of ice-contact and outwash-plain origin and range in thickness from less than a foot to more than 150 feet. These deposits store large amounts of water and yield 250 to 600 gpm (gallons per minute) to industrial and irrigation wells.

The glaciolacustrine deposits consist of varved clay and silt, which is essentially impermeable. These deposits confine water in underlying outwash deposits and also hold up perched water in overlying eolian sand. The sand yields as much as 100 gpm to a properly constructed well.

The consolidated rocks are sandstone and shale, interbedded layers of basalt, and crystalline rocks. On the average, these rocks yield 10–15 gpm to wells, but the sandstone and shale yield larger quantities, as much as 550 gpm, to a few wells.

The ground water in north-central Connecticut is of the calcium bicarbonate type, has a low mineral content, and is suitable for most purposes. The sandstone and shale generally yield moderately hard to very hard water.

EOLIAN CALCARENITE AS A PALEOCLIMATIC INDICATOR

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Eolian calcarenites (also known as calcareous eolianites or merely "dune rocks") are believed to be restricted to quite specific environments in the geologic past and subject to quite specific climatic conditions—*i.e.*, continental shelves and coastal plains affected by the extreme eustatic oscillations, such as characterize glacial/interglacial cycles, but only in those latitudes and under such ecologic conditions that permit a very large build-up of organogenic clastics.

World-distribution studies show that Pleistocene eolian calcarenites range from approximately 35°N. to 35°S. Lat.; they reach their greatest abundance along coasts that are in the present semiarid belts, where the continental shelves were widest during the periods of Pleistocene low sea level, and particularly where on-shore winds must have been strong and constant. Many pure white quartz sands found today on coastal plains are believed to be leached residues of quartz-bearing calcareous beach and dune sands. Application of this information to ancient calcarenites may provide valuable paleoclimatic indications.

METHODS OF ESTIMATING THE AGE OF COMMON LEAD MINERALS

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The time of deposition of common lead ores can be estimated from the ratios Pb^{206}/Pb^{204}, Pb^{207}/Pb^{204}, and Pb^{208}/Pb^{204}. The methods for making such estimates will be outlined and compared. Certain lead ores having anomalously high lead isotope ratios appear to have been in contact with higher than average concentrations of uranium and thorium during a single period in their histories. The isotopic data are useful in estimating the time at which the extra contributions of radiogenic lead occurred. In one case where both mass spectrometric and spectrochemical data are available, the results support the hypothesis that the anomalous leads have received their radiogenic additions from crustal rather than subcrustal sources.

QUANTITATIVE METHODS USED ON GROUND-WATER INVESTIGATIONS

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Since the beginnings of quantitative ground-water hydrology in Europe, a century ago, interest in the development of quantitative tools in this subject has spread over the world to enlist workers from many fields of science. Much of the development of methods, tools, and skills for quantitative appraisal of ground-water sources has occurred within the past few decades, and now, because of the

great strides made in this period, hydrologists can determine the ground-water potential of an area with the same degree of accuracy obtainable in the appraisal of surface water.

With Darcy's development of the law governing fluid permeation through sands and with Dupuit's application of that law to the problem of radial flow toward a pumped well, the development of water supplies from wells was placed on a rational basis.

An important milestone was Theis' development in 1935 of a solution for the nonsteady flow of ground-water, which enabled hydrologists to forecast the yield of wells and to appraise their influence in both time and space.

RADIOCARBON DATES AND PLEISTOCENE CHRONOLOGY

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Radiocarbon dates have two principal applications to late-Pleistocene stratigraphy: (1) measurement (within the range of C^{14} dating) of rates of pertinent geologic processes such as rate of sedimentation in various environments, rate of postglacial recovery of the crust, rate of rise of sea level, rate of change of atmospheric and surface-seawater temperatures, and rate of advance and retreat of glaciers; (2) correlation of sedimentary units in widely separated areas, making possible the establishment of contemporaneous events. Thus the time relation between glaciations on two continents and between glaciation and pluvial climates in two different regions can be inferred. In a larger sense determination of the regional extent of contemporaneous climatic change becomes possible.

Earlier late-Pleistocene chronologies, based on other measurements and on estimates, show varying degrees of departure from the chronology based on C^{14} dates.

RUBIDIUM-STRONTIUM AGE METHOD AND THE AGE OF ANCIENT GRANITIC ROCKS

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The decay of Rb^{87} to Sr^{87} is a useful chronometer in the determination of geologic time. Sufficient ubiquitous minerals such as biotite, muscovite, and potassium feldspar can be dated by this method. The micas are especially useful because of the very limited substitution in their lattice of strontium by potassium. The ratio of radiogenic strontium to rubidium in a mineral is more resistant to alteration by geologic processes than either the A^{40}/K^{40} ratio or the various Pb/U ratios and Pb/Th ratios.

Studies on the isotopic composition of strontium in granites show that some granites exhibit sufficient enrichment in Sr^{87} for the whole rock so that the ratios of radiogenic strontium to rubidium can be measured with sufficient accuracy to give an accurate age.

Ages derived from both the bulk rock and from separated minerals will be given for several rocks. Ages on associated pegmatitic minerals will also be given.

DATING BY THE LEAD-ALPHA METHOD

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The technique for determining the age of radioactive accessory minerals—zircon, monazite, and xenotime—in igneous rocks from the total lead-alpha activity was first proposed in 1952 by E. S. Larsen, Jr., N. B. Keevil, and H. C. Harrison.

The work described here was a co-operative effort involving H. W. Jaffe, F. E. Senftle, C. L. Waring, and the author.

Monomineralic concentrates of 100 milligrams are isolated from the rock. Alpha-activity measurements of the uranium and thorium concentrations, obtained by thick-source alpha counting in an ionization chamber or scintillation counter, have an accuracy within ± 5 per cent. The lead content is determined by emission spectrography with the lower limit of sensitivity of about half a part per million and has an accuracy within 5–10 per cent.

The age of the accessory minerals can be applied to the age of the enclosing rock provided: (1) the

lead in the accessory minerals is radiogenic, (2) neither parent nor daughter product has lost or gained since the time of crystallization of the accessory minerals; (3) the accessory minerals are contemporaneous with the other minerals.

Excellent agreement of ages has been obtained on zircon, monazite, and xenotime from the same or related rocks. These minerals contain widely different amounts of lead and alpha activity and different proportions of uranium and thorium. Thus it is believed that no significant quantity of primary lead is present in these minerals. For evaluating the applicability of the method to the solution of geologic field problems, age determinations have been made on accessory minerals from well-dated igneous rocks ranging in age from Miocene to late Precambrian. The data agree with the geologic sequence of events and with the time scale of Holmes.

Comparison of lead-alpha ages with those of other methods on some Precambrian rocks indicates that the lead-alpha activity ages are too young. Some data indicate loss of lead by partial or complete recrystallization of zircon by later metamorphic processes.

IRON MOUNTAIN THRUST FAULT AT WATAUGA DAM, TENNESSEE

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Construction of Watauga Dam by the Tennessee Valley Authority in Carter County, Tennessee' has exposed one of the larger overthrusts of the Southern Appalachians. The Iron Mountain thrust was seen in the excavations for the spillway plaza, the spillway and diversion tunnels, the valve chamber, the power tunnel, and the dam foundation. With the exception of the spillway plaza, all exposures of the fault at this site will be covered upon completion of the dam.

The Iron Mountain fault and the Holston Mountain fault are parts of the same downfolded overthrust; the fault plane separates the Lower Cambrian clastics in the Shady Valley syncline from the underlying Cambrian and Ordovician sediments of the Valley of East Tennessee. The Mountain City window separates the Iron Mountain fault from its roots in the Unaka Mountains to the southeast.

The detailed structural features of which studies were made include (1) folding, faulting, and jointing of the dolomite and shale in the footwall; (2) folding, faulting, and jointing of the quartzites in the hanging wall; (3) evidence of the direction of movement of the main fault and of the related faults in the hanging wall and footwall; (4) petrographic study of the variation in the deformation and alteration in both the hanging wall and foot wall.

BOULDER-FILLED DIKES NEAR BURLINGTON, VERMONT

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In several trachyte porphyry (bostonite) dikes on Shelburne Point, southwest of Burlington, Vermont, there are numerous inclusions of Adirondack-type igneous and metamorphic rocks, quartzite, and dolomite identical with allochthonous lower Cambrian formations east of the Champlain thrust, and limestone, dolomite, and shale similar to autochthonous lower and middle Ordovician formations of the central Champlain Valley. The dikes are about a mile west of the trace of the east-dipping Champlain thrust, and their inclusions are assumed to have come from below. If this be true, the lower Cambrian section is present under the central Champlain Valley even though it is overlapped a few miles west by the upper Cambrian Potsdam sandstone on the faulted east flank of the Precambrian Adirondack dome. The major thrusts of the eastern Champlain Valley need not represent more than a few miles of low-angle displacement.

UTILIZATION OF GROUND WATER IN SUFFOLK COUNTY, LONG ISLAND, N. Y.

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Suffolk County, New York, one of the fastest-growing counties in the United States, has an area of 920 square miles—about three-quarters as large as Rhode Island. Since 1950, the number of in-

dustrial firms has increased more than 60 per cent, to 3863. The population increase during the same period was of comparable magnitude, and the population at the present time is more than 450,000.

Agriculturally, Suffolk County is among the leaders in producing potatoes and late-season cauliflower. Continued industrial growth, at an increasing rate, is a strong possibility because of the presence of extensive areas of relatively cheap land, an adequate supply of water of excellent quality, and an active program to encourage the location of industry within the county.

Ground water is the principal source of supply in Suffolk County. The major uses are for public supply, industry, and agriculture. In 1955 these were, respectively, 41 per cent, 33 per cent, and 26 per cent of the total 24,320 million gallons pumped.

At present, the chief ground-water problems are sea-water contamination at a few wells and corrosion due to the use of untreated water of low pH. Future problems that may arise, if ground-water withdrawals continue to increase, are: (1) more extensive sea-water contamination; (2) permanent depletion of ground-water storage, especially if Suffolk County is extensively sewered; (3) local increases in ground-water temperature due to artificial recharge; (4) chemical contamination of the ground water by industrial wastes, cesspools, and fertilizers. These potential problems necessitate careful evaluation and planned development of this important natural resource that is so necessary to the future growth of the county.

DOLOMITE IN THE FLORENA SHALE OF KANSAS

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The Florena shale is a thin, chemically variable sedimentary unit (early Permian), traceable in outcrop from southern Nebraska to northern Oklahoma. Over a north-south distance of about 100 miles, in central Kansas, the Florena contains appreciable quantities of the mineral dolomite (10–80%), usually in its upper part. Florena dolomite is attributed to early diagenetic alteration of fine-grained calcite sediments deposited in a relatively deep, poorly ventilated, stratified portion of a warm, epeiric sea. Several observations support this interpretation: (1) evaporites present higher in the Permian sequence show that hydrographic conditions for restricted circulation did in fact develop shortly after Florena deposition; (2) overlying and underlying limestones are not dolomitized; (3) the stratigraphic section thins immediately north and south of the dolomite area and contains faunal evidence of shallow-water deposition; (4) dolomite is present as euhedral crystals, mostly smaller than .01 mm; (5) an increase in dolomite is associated with definite changes in the composition and abundance of the benthic but not the pelagic fauna; (6) an increase in dolomite is associated with a decrease in the average grain size of bioclastic material and with an increase in the proportion of unbroken carapaces of certain delicate ostracodes; (7) calcareous fossils in rocks of medium- and high-dolomite content show no evidence of recrystallization.

THIRD CLASS OF ARCUATE STRUCTURES

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The world literature on arcuate structures reveals that before 1936 geologists had applied the term "arcuate structures" to large curved uplifts only (the great "ox-bow" made by the Carpathian-Transylvanian Alps in central Europe and the long series of "festoon island chains" that border the eastern coast of Asia). Before 1914 few were interested in the causes of the great curved uplifts. In 1914 William H. Hobbs' contribution to the problem led to widespread interest in genesis of arcuate structures. Much laboratory testing was done, usually with very simple methods, and several important problems were left unsolved.

In 1936, new experiments which more closely simulated conditions in nature were begun at The Institute of Sciences at Kansas City. There it was often demonstrated that good examples of positive (uplift) arcuates can be formed almost at will in globe-shaped coatings of suitable plastics, through the use of controlled force-sets. Curved depressions sometimes were shaped, to which the term "negative" arcuates was applied.

In addition to the simple arcuates, there were occasional examples of compound and also complex curved forms of both classes. Through studies of data supplied by the U. S. Coast and Geodetic

Survey and other authorities, it was found that examples of each of the six types occur at various places over the world.

Extensions of early investigations led to studies of the voluminous data of Oceanography, Vulcanism, and Seismology. Recently it has been found that Earth's worst centers of crustal disturbance are situated in great curved belts or zones at depths of many scores of miles below the deepest ocean bottoms. These great belts of dynamic centers clearly have both the form and dimensions that mark them as Earth's largest known arcuates—characteristics believed to warrant listing them as a Third Class of Arcuate Structures.

This paper briefly describes five of the largest of these subterranean arcuate structures whose collective length exceeds 7000 miles, with profound effects upon geology and human welfare.

STRATIGRAPHY AND STRUCTURE OF THE STISSING AREA, DUTCHESS COUNTY, NEW YORK*

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Stissing Mountain is underlain by Precambrian gneiss, unconformably overlain by gently dipping to horizontal Poughquag quartzite of Early Cambrian age. Northeast of Pine Plains Poughquag quartzite crops out along a strike of N. 50° E. and dips southeast. For about 9 miles southward it is possible to follow gently dipping carbonate-bearing strata that overlie the quartzite along a strike ranging from N. 50° E. to almost east-west.

Stratigraphy

Carbonate Rocks

These rocks range from Early Cambrian to Early Ordovician in age. Fossils found in Lower and Upper Cambrian and in Lower Ordovician rocks, in a succession that shows no indication of faulting, establish the stratigraphic sequence. Lithologic and paleontologic study indicate five characteristic lithologic zones in the Stissing dolomite of Early and Middle Cambrian age and three in the Pine Plains formation of late (?) Cambrian age.

The Ploughquag quartzite is about 250 feet thick. The overlying Stissing dolomite is 500 feet; its top is marked by dark beds that carry *Prozacanthoides stissingensis* Dwight and *Paterina stissingensis* Dwight.

The Upper (?) Cambrian Pine Plains formation is a variable assemblage comprising dark, sandy, and argillaceous dolomites at three horizons with intervening heavier-bedded and lighter-colored dolomites accompanied by edgewise conglomerates, oölitic beds, and cryptozoon reefs.

The Upper Cambrian Briarcliff dolomite comprises 700 feet of dominantly light-colored, fairly heavy-bedded dolomites and calcdolomites with some intervening beds of dark impure dolomite. In its lower half it carries *Prosaukia briarcliffensis* Lochman and *Plethemetopus knopfi* Lochman, which establish its age as Late Cambrian, probably early Trempealeau.

The Lower Ordovician rocks comprise the Halcyon Lake formation made up of sandstones, dolomites, and calcdolomites, estimated to be 350 feet thick, and the Rochdale limestone, possibly 750 feet thick. The Halcyon Lake carries *Ozarkispira*, *Ellesmeroceras* sp., *Ectenoceras* sp., and a small gastropod similar in form to *Sinuopea*. The age is thereby fixed as earliest Ordovician (Gasconade).

The Rochdale limestone is predominantly limestone with some dolomite. It apparently overlies conformably the Halcyon Lake formation, and on the east side of Shekomeko Valley it appears to pass conformably into about 500 feet of beds resembling the Copake limestone. The Rochdale limestone carries *Lecanospira*, *Leseurilla* sp., *Bassleroceras* sp., *Clitendoceras* sp., and small syntrophid brachiopods, considered to be a typical midlde Lower Ordovician assemblage.

Phyllitic Pelites and Psammites

The area underlain by these rocks is mapped as undifferentiated pelites and psammites, probably of Early Cambrian age; and undifferentiated pelites and psammites with subordinate impure limestone beds, probably Early Ordovician.

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Structure

It has been generally considered that pelitic and psammitic rocks occupy higher topography and that the carbonate sequence occurs in the northward-trending valleys. The pelite-psammite assemblage, called the "Taconic sequence," has been considered by many workers to overlie the carbonate sequence conformably or unconformably, in a gently rolling mantle, broken in places by imbricate faults of prevailing eastward dip.

The present work shows that the carbonate rocks surrounded by a slaty and phyllitic assemblage occupy successively overlying plates, so arranged that in the western part of the area plates of relatively flat-lying rocks of prevailing southward dip overlie each other up to 300 or 400 feet above the adjoining valley floor. In places carbonate plates are surrounded by slaty rocks that dip under carbonates on the north side and overlie carbonates on the southern end. In some places slates of Lower Cambrian aspect cut across gently dipping carbonates that range in age from Cambrian to Ordovician. These structural relations disprove the interpretation that the slates rest unconformably upon erosion windows of underlying carbonates.

The pelite-psammite assemblage has been affected by intensive penetrative movement throughout; the original bedding is everywhere displaced by recumbent folds accompanied by imbricate thrusting that has torn out the limbs of folds until original bedding is recognizable only as lenticles and streaks. In this way original stratification has been completely transposed and in some places is clearly discordant to the structure of the carbonate rocks.

Fabric analysis of the rocks around Stissing Mountain has shown clearly the influence of at least three and perhaps more movement plans differing in trend from 60° to 80°. These different trends suggest the influence of several pulses of orogeny, but it requires further and more detailed fabric analysis to determine the possible time relations. In the meantime it is futile to speculate on where the discordant pelite-psammite assemblage was originally deposited. The similarity of biofacies in the carbonate sequence and in the pelitic assemblage in the Hudson Valley certainly suggests a facies transition between the two sequences, but it is nevertheless certain that such a transition can neither be proved nor disproved in the areas of strong tectonic displacement and deformation that extend from Dutchess County northward. That the material of the "Taconic sequence" has been derived from a depositional environment far to the east is a pure speculation. On the other hand the evidence derived from both megafabric and microfabric study indicates that it was not deposited *in situ* as flat-lying formations crumpled by small crenulations and locally affected by imbricate thrusting.

POTASSIUM-ARGON DATING OF SEDIMENTARY AND IGNEOUS ROCKS

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This laboratory has developed techniques for dating samples of low radiogenic argon content. Results of three principal lines of study utilizing these techniques will be reported: (1) ages of a series of well-classified glauconites from New Zealand ranging from the Cretaceous (55 million years) to the Miocene (20 million years); (2) ages of two near surface igneous micas from Sutter Buttes, California less than 2 million years in age; (3) ages of a series of related plutonic igneous micas from the Sierra Nevada about 90 million years in age.

NEW POTASSIUM-ARGON DATES ON PLUTONIC ROCKS

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The K-A age method has been applied successfully to numerous geological problems, among them the absolute age relationships of the rocks in the area of the city of New York. Ages ranging from 1.0 to more than 1.3 billion years suggest a fairly complex history for the rocks of the New Jersey and Hudson Highlands. Ages close to 400 million years for the metamorphic rock of the Manhattan Prong, east of the Hudson River, distinguish the prong as a geologic province separate from the Highlands.

The K-A age method may be used to date certain types of ore deposits.

Studies are being made on various potassium minerals from the same pegmatite in an effort to estimate their relative argon retentivity. Pegmatites in the Southern Black Hills are ideal for this purpose because they are old and their geologic history has been simple since the time of intrusion.

RADIOCARBON DATES AND ARCHAEOLOGY

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The prime importance to archaeology of an objective method for counting time cannot be over stated. Since archaeology alone makes possible the extension of our knowledge of man's early attempts to develop civilization on this planet beyond the limits of written records, it is a historical science. As such it depends on dates that are as accurate as possible to serve as a basis for the establishment of a given chronology. However, before 1950 the commonly available archaeological chronologies for prehistoric events could be established only on a relative basis. Thus they lacked precision and were often badly in error. From the beginning the radiocarbon method provided archaeologists with a new research tool that already has made invaluable contributions. Thus far several thousand determinations have been made on archaeological samples from all over the world, and the basis for a chronology for the last 40,000 or so years is beginning to emerge. Furthermore, for the early lithic assemblages from sites that were occupied during the Last Glaciation in Europe and North America, it is now possible by a single method to collate chronologies in several allied fields. This objective method of solving chronological problems of an interdisciplinary nature is of fundamental importance, especially with respect to the materials of Late Pleistocene age. Future research along these lines on a carefully determined regional basis will inevitably provide new and valuable data for the extension of the paleogeographical or environmental approach to the interpretation of archaeological materials from sites that were occupied some 40,000 to 10,000 years ago.

TEXTURE AS A BASIS FOR CORRELATION OF TILL SHEETS IN CHAUTAUQUA COUNTY, WESTERN NEW YORK*

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Mapping of surficial deposits in six quadrangles in Chautauqua County shows the presence of at least four distinct till sheets of presumed Cary age. Although the coarse component of the tills varies laterally in composition and coarseness, each sheet is characterized by a range of sand-silt-clay ratios narrow enough to afford a basis for mapping and correlation.

The oldest and southernmost till sheet is that associated with the Early Cary (?) Binghamton moraine which abuts against drift-free uplands at 2000 feet above sea level in the southeastern corner of the county. Deposition during intermittent stagnation of the receding Binghamton ice sheet produced somewhat disconnected valley-choking kame complexes referred to by Leverett as the inner and outer positions of the Cleveland moraine. A minor glacial readvance of probable late Middle Cary age deposited a weak end moraine and thin till sheet, similar to that mapped in Pennsylvania by Shepps as the Lavery moraine. Overlying the Lavery till is a distinctive chocolate-brown clay till texturally and pedologically similar to the Defiance till of eastern Ohio. Except where tongues of Defiance-like clay till project southward in a few main valleys, this drift sheet is obscured by the Late Cary Lake Escarpment moraines which correspond in part at least to the Valley Heads moraine of the Finger Lakes region.

STRATIGRAPHY OF THE PRE-SILURIAN SEDIMENTARY ROCKS IN MAINE†

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Beneath the abundantly fossiliferous Silurian rocks in Maine are intensely deformed rocks dominated by phyllite and quartzite. Angular unconformities in several places clearly show the contrast

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† Publication authorized by the Director, U. S. Geological Survey.

between the Silurian and the older rocks. During the past 100 years the older rocks have yielded fossils of Early and Middle Ordovician age in eastern Aroostook County, and of Middle Ordovician age elsewhere at three widely separated localities. All the fossils have been recovered from rock types that are rare in this area: trilobites and brachiopods from unusually calcareous siltstone and graptolites from black slate in Aroostook County, graptolites from graphitic slate interbedded with chert at Danforth and Wassataquoik Stream, brachiopods from tuff at Somerset Junction. The widespread phyllites and quartzites seem to be devoid of fossils. Future work should include a search for additional occurrences of uncommon rock types that might be fossiliferous and detailed mapping to tie these to the more common rocks.

BAHAMIAN LIMESTONE SEAS

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The Great Bahama Bank, outstanding modern example of a limestone shelf sea, is being used as a natural laboratory in which to study marine materials and processes. A large area of the northwestern part of the Bank is being systematically sampled and mapped from a base of operations at the Lerner Marine Laboratory of the American Museum of Natural History on Bimini. This report records the progress made to date on the study of sediments and associated organisms.

Sediments in the Bimini area represent three types of carbonate sands: skeletal grains, faecal pellets, and oölite. The skeletal sands, composed chiefly of foraminifers, calcareous algae, mollusks, and corals, are quantitatively the most important type. Faecal pellets are widespread and locally dominate the sediment. Oölite is abundant along a strip a mile or so in width just east of the marginal line of cays.

The composition of animal and plant communities is closely correlated with the kind, texture, and thickness of unconsolidated sediment. Conversely, the characteristics of the bottom are greatly influenced by organisms that originate, modify, and trap sediment. Movements of three water masses (Florida Straits water, Bank water, and water partially trapped in the Bimini lagoon) also appear to play an important role in the distribution of organic communities in the Bimini area.

STRATIGRAPHY OF THE SUTTON MOUNTAINS, QUEBEC; KEY TO STRATIGRAPHIC CORRELATION IN VERMONT

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The axis of the Green Mountain-Sutton Mountain anticlinorium is depressed in the vicinity of Danville, Quebec. The rocks exposed in the west limb of the anticlinorium have been traced through this depression into rocks in the east limb. The sequence Pinnacle, White Brook, West Sutton, Gilman, Dunham, and Oak Hill, in the west limb of the anticlinorium, has been traced into the West Sutton as mapped in the east limb in the present study; the Sweetsburg and the "Sillery" east of Actonvale, Quebec, are equivalent to the Mansonville; and the Stanbridge is equivalent to the Beauceville.

The rocks beneath the Stanbridge in the west flank of the Green Mountain-Sutton Mountain anticlinorium have been traced from southern Quebec through northwestern Vermont into the Cambrian section of west-central Vermont. The Stanbridge is equivalent to the Morses Line of Shaw (In press) in northwestern Vermont and, by its lithology and stratigraphic position, is probably equivalent to the Hortonville of west-central Vermont.

The rocks east of the Green Mountain-Sutton Mountain anticlinorium in Quebec have likewise been traced southward into Vermont. The Beauceville has been traced into the Moretown as it is mapped in north-central Vermont. The upper part of the Mansonville is at least in part equivalent to the Stowe, and the lower part of the Mansonville has been traced into the Ottauquechee. The stratigraphic relations beneath the Mansonville and Ottauquechee remain obscure.

INTERRELATIONS BETWEEN GROUND WATER AND ENGINEERING STRUCTURES

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There is an impelling and pervasive relationship between the principles that govern ground-water flow and engineering structures, which if neglected by the geologist or engineer leads to loss or disaster, but which if taken account of leads on to success or fortune (with apologies to William Shakespeare).

Some aspects of these relationships will be illustrated by examples of the slides at Panama where the impossibility of draining the Cucaracha formation, coupled with oversteepened slopes, led to disaster; the failure of the St. Francis Dam where the solubility of minerals within an embankment led to failure and the death of 400 people; the slide at the Ft. Peck Dam brought about by pore-pressure and bentonite within the foundation; the Chesapeake-Delaware Canal where slides were confined to only one side because of ground water; the proposed Florida canal where fear of ruining ground-water supplies appeared to the writer groundless; the argument as to the source of artesian head illustrated by the proposed canal from New York to the Delaware River; the Hershey Chocolate Co. case where pumping in quarries lowered the water table in valuable company wells, with similar relationships related to heavy pumping at Friedensville, Pa.; the probable cause of the Niagara River power house disaster where an unlined canal appeared to have been the culprit. Note that nothing has been said of the immense importance of ground water in the disposal of hot wastes from modern industrial plants.

AGE OF METEORITES

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The age of meteorites is important to our understanding of the genesis of stars, our solar system, and the earth. Four methods are now used to measure the time since chemical differentiation occurred in meteorites: (1) the lead-lead method; (2) the potassium-argon method; (3) the rubidium-strontium method; and (4) the helium method. The techniques of and the answers obtained by those methods will be discussed.

RELATION BETWEEN FRESH AND SALTY GROUND WATER IN SOUTHERN NASSAU AND SOUTHEASTERN QUEENS COUNTIES, LONG ISLAND, N. Y.

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U. S. Geological Survey, Mineola, New York

An investigation of the geology and ground-water conditions in a part of southern Long Island, including the construction of eight deep and five shallow test and observation wells, has been completed by the U. S. Geological Survey in co-operation with the Nassau County Department of Public Works and the New York State Water Power and Control Commission.

In this area are the four principal water-bearing units generally recognized in western Long Island. More than 160 mgd (million gallons per day) of fresh water has been pumped from these deposits in the area. Salty ground water is encountered in some wells that penetrate the upper three units. Although the presence of the salty water constitutes a threat, existing fresh-water supplies apparently are in little immediate danger.

The salty ground water has chloride concentrations ranging from 40 to about 18,000 ppm (parts per million), generally more than about 2000 ppm. It occurs in several bodies, seaward of and beneath the fresh water in the respective aquifers, and is in contact with the fresh water through zones of diffusion. The largest salt-water body, confined under artesian pressure, is in the Jameco gravel and the Magothy (?) formation beneath extreme southwestern Nassau County and adjoining areas. This body is thought to have occupied approximately its present extent since about 1900. It probably has been and is now encroaching, very slowly, because of increased pumping from the fresh-water bodies and possibly as a result of a postglacial rise of sea level. The rate of encroachment under present conditions probably is less than 100 feet per year.

Application of the Ghyben-Herzberg formula to compute depths to salt water beneath fresh water gave erroneous results. More nearly accurate depths were computed from a formula adapted from Hubbert.

"STONES RIVER GROUP" IN PENNSYLVANIA*

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The invalidity of the correlation of the lower Middle Ordovician in the Appalachians with the Stones River group of the Central Basin of Tennessee has been discussed by workers in Tennessee, Virginia, and Maryland. The term "Stones River" has stood alone for years in the nomenclature of rocks of Chazy age in south-central Pennsylvania.

A three-fold subdivision of upper and lower calcilutites and dolomites, and a middle impure, cherty member exceed 1000 feet in the southeast belts, Franklin County. Westward, thinning by convergence and overlap to less than 100 feet occurs in central Pennsylvania, and the upper calcilutite member constitutes the Loysburg limestone of that area. Northeast of Franklin County thinning occurs to the Harrisburg area where the lower and middle members are overlapped by the upper member on the Harrisburg arch; the upper member passes east of Harrisburg into the high-calcium Annville limestone. Southward into Maryland boundaries of the three members are not clearly drawn in the St. Paul group, but several faunal and lithic similarities are evident.

Interbedded calcilutites and dolomites ("transitional beds") up to 400 feet separate rocks of definite Chazy and Beekmantown age. These are assigned a tentative post-Beekmantown age and are believed to lie above a regional disconformity of considerable relief.

Correlations into the New York standard indicate that the Pennsylvania "Stones River" embodies all of the type Chazy with the upper beds extending into the Pamelia and possibly the Lowville. Paleogeographic significances and proposed revisions of the "Stones River" of this area are discussed.

LEAD-ALPHA AGES OF RHODE ISLAND GRANITIC ROCKS COMPARED TO THEIR GEOLOGIC AGES

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U. S. Geological Survey

Field studies have shown at least three groups of granitic rocks in Rhode Island. The Scituate granite gneiss and the Esmond granite with their affiliates are oldest (Devonian ? or older), the Cowesett granite and the Quincy granite are intermediate (Mississippian ?), and the Westerly granite and the redstone are youngest (Late Carboniferous or younger). The two older groups are overlain unconformably by sedimentary rocks of Pennsylvanian age of the Narragansett Basin, and the youngest group is intrusive into these Pennsylvanian rocks. The geologic evidence in Rhode Island does not give accurate indications of how much older or younger than the Pennsylvanian rocks these groups are. Lead-alpha age determinations on zircon and monazite from the three groups of granitic rocks gave mean ages of 301 ± 12 million years, 263 ± 6 million years, and 230 ± 24 million years, respectively. These are internally consistent, agree with the geologic evidence, and are within the accepted age limits of the geologic time scale for the Devonian, Mississippian, and Pennsylvanian periods, respectively.

TERTIARY GEOLOGY OF PINE VALLEY, NORTH-CENTRAL NEVADA

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Five continental formations compose the post-Paleozoic beds of Pine Valley, Eureka County, Nevada. The lowermost two are not well dated. They consist of the thick andesitic lavas of the Cortez Mountains, which rest unconformably on Carboniferous limestones, and 2000 feet of sandstones and

* This paper given with permission of the Pennsylvania Topographic and Geologic Survey.

conglomerates which rest upon them in sedimentary contact. This series of clastics contains andesite pebbles at the bottom and Paleozoic pebbles at the top. It is devoid of pyroclastic elements.

These two formations are disconformably overlain by 2700 feet of Upper Miocene beds, which consist, from bottom to top, of lapilli tuffs, volcanic breccias, tuffaceous sandstones, and volcanic conglomerates, and vitric tuffs interbedded with diatomite beds. Horizontal Pleistocene lake beds lie with angular unconformity on the Upper Miocene. In the center of the valley, they consist of clays and limestones interbedded with vitric ash. Toward the Pinion Range to the east, they grade into fanglomerates which are the result of its upfaulting. The thick rhyolite flows of the Palissade Canyon are post-Miocene and presumably Pliocene.

RELATION BETWEEN THE WATER TABLE AND THE ZONE OF AERATION

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The zone of aeration, its relation to the water table, and the movement of moisture within it have been studied at Seabrook, New Jersey. The "zone of high capillary conductivity" lies directly above the water table. The suction potential and the moisture content of the soil at any given point in this zone depend upon the height of the point above the water table. Moisture conditions in the overlying zone, the "zone of low capillary conductivity," are independent of the water-table position and independent of evapotranspiration in progress closer to the surface. The "zone of climatic control" coincides with the effective root zone, and its moisture content is directly controlled by precipitation and evapotranspiration.

Water from precipitation penetrates the unsaturated material preceded by a "wetting front." The depth to which a given rainfall penetrates depends largely upon the thickness and moisture condition of the "zone of climatic control." If there is insufficient water to wet the entire thickness of unsaturated material to field capacity, the "wetting front" stabilizes and dissipates above the water table. Ground-water recharge can then occur only by slow drainage. The rate at which a given rainfall penetrates the unsaturated material depends largely upon its magnitude.

METAMORPHIC GEOLOGY OF THE MIDDLE HADDAM AREA, CONNECTICUT: A PROGRESS REPORT*

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East of the Triassic border fault near Middletown are portions of four gneiss domes, mantled by predominantly schistose stratified metamorphic rocks ranging in age up to Devonian (Littleton formation). Within the mantling strata are two major unconformities characterized by superimposed strata of a coarsely clastic facies. The upper unconformity is believed to represent the Taconic orogeny. The lower is distinctive for the sedimentary nature of its contact with the underlying rocks of predominantly volcanic origin and the massive granitoid rocks intruding them. The granitoid rocks compose all the observed core of the northwesternmost dome and show complexly intrusive relationships into the older metavolcanic strata in the west-central dome.

The arcuate structure of the domes contrasts strongly with the almost cuspate nature of the intervening synclines. Minor structural elements suggest that the central geneissic masses moved upward relative to the mantling strata, possibly as the result of density difference (after J. B. Thompson) An en echelon pattern present in the western domes could be explained as resulting from upwelling. of gneiss along planes across which there is relatively low stress due to left lateral shear in the region. Independent evidence of such shear is found in adjacent areas. The principal deformation and simultaneous metamorphism has affected the Siluro-Devonian strata and is considered to be Acadian.

Metamorphism, symmetrically disposed about the domes, ranges from the kyanite-staurolite zone to the sillimanite zone toward the gneissic cores. Thermal energy for metamorphism is believed to have been derived from initial temperature distribution and deformation.

* Work performed in large part under grant G-2155, National Science Foundation.

STRUCTURAL GEOLOGY OF COPPER CREEK THRUST BLOCK, NORTHEAST TENNESSEE*

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The Copper Creek thrust block crosses parts of Grainger, Hancock, and Hawkins counties, northeast Tennessee, and extends beyond for many miles, both to the northeast and southwest; it is one of the major structural units of the Southern Appalachian Valley and Ridge Province. The block is bounded on the southeast by the Saltville fault.

Paleozoic marine and nonmarine sedimentary rocks, ranging in age from Early Cambrian to Late Mississippian, underlie the area; they form a sequence 15,000 feet thick on the Copper Creek block. The strata, formerly flat-lying sediments of the Paleozoic Appalachian geosyncline, have been folded and faulted without cleavage or metamorphism.

The major structure of the Copper Creek block is the Greendale syncline; its northwest normal limb forms a southeast-dipping monoclinal sequence that characterizes most of the block. A gentle culmination of plunges in this syncline occurs in the central part of the area.

In northeastern and southwestern parts of the area stratigraphic displacement on the Saltville fault is 11,000–15,000 feet (Lower Cambrian of Saltville block against Mississippian of Copper Creek block); in the central part, however, another thrust (Stone Mountain) appears. The Stone Mountain thrust coincides with a re-entrant to the southeast in the Saltville fault trace and decreased stratigraphic displacement on the Saltville fault (4400 to 200 feet; Lower or Middle Cambrian against Lower Ordovician).

Isoclinal overturned folds characterize the Stone Mountain block; these folds strike slightly more to the northeast than the Stone Mountain fault trace and plunge uniformly southwestward.

Normal faults of small displacement cut both folds and thrusts on the Copper Creek and Stone Mountain blocks.

The Stone Mountain thrust is inferred to be mechanically analogous to the Beaver Valley fault similarly located along strike 70 miles to the southwest; both cause comparable changes along the Saltville fault. All major thrusts in the area are inferred to be high-angle faults that originated from broken overturned folds. This structural pattern suggests deformation of a thick sedimentary cover independent of the underlying "basement." Such a pattern and the inferred depositional history of the area argue against the existence of a "Tazewell axis" or an "Adirondack axis" in northeast Tennessee.

APPLICATION OF GEOLOGY TO THE INVESTIGATION OF WATER RESOURCES

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The applications of geology to the study of water resources, especially surface water, until recent years has attracted little attention because, except in arid regions, water appeared to be plentiful. In contrast, the application of geology to the exploration for and the development of metalliferous deposits and hydrocarbons has progressed far during the past 75 years. As a result of the drought years of the 1930's, with short surface-water supplies, and the improvement of well construction and equipment for developing ground-water supplies, plus the rapidly expanding industrial growth brought on by the war and postwar conditions, there has been a growing awareness of the vital part water resources play in the increasingly complex national economy. This has created a demand for thorough and scientific study of water resources, and today there is urgent need for the college and university curricula to emphasize the application of geology to ground-water hydrology in order that a reservoir of capable geologists with hydrologic training may be available to enter this important and growing field.

Geologic techniques used in ground-water investigations, though similar in many respects to those used in the investigation of other mineral resources, must take into account the fact that ground water is replenishable.

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PETROGRAPHY OF SOME PACIFIC ATOLL DOLOMITES

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Dolomite in the subsurface of atolls in the Pacific is the result of at least two processes; each produces characteristic rock textures.

Alternating layers of calcite and secondary dolomite form banded cavity fillings in the deeper parts of the Funafuti boring. Deposition of calcite and conversion to dolomite is cyclic and probably took place in a chemically variable, shallow-water environment, before the host rock sank into deeper water in which relatively steady-state chemical conditions prevailed. Thus rate of subsidence may exert some control over dolomitization. Cullis has shown that a small percentage of the dolomite in the Funafuti boring was precipitated from sea water in calcite-lined voids. Despite complete dolomitization, many details of the original rock texture remain.

In cores from Eniwetok dolomite forms single crystals as crystal mosaics some of which have coalesced; original textures have been destroyed. In some Eocene limestones from Eniwetok euhedral dolomite crystals are found within high-magnesian algae. The crystals are structurally Mg-deficient and contain submicroscopic scattered calcite particles. The writer suggests that the dolomitized algae result from crystallographic ordering of originally randomly distributed Ca and Mg ions in the high-Mg algal calcite. Presumably this ordering initiated on nuclei of dolomite inherent in the organic algal skeleton. Extensive dolomitization requires the addition of some magnesium from sea water. This type of dolomitization might take place at any depth.

Dolomitized limestones from Kita-Daito-Jima show textures and replacement phenomena related to both the Funafuti and Eniwetok types.

The $MgCO_3$ content is not a reliable indicator of dolomitization. A sample from the subsurface of Kita-Daito-Jima contains only 2.8 per cent $MgCO_3$ by weight, but small, scattered, euhedrons of dolomite are present. In contrast, a sample from a depth of 25 feet in the Funafuti boring contains 16 per cent $MgCO_3$ but no dolomite. Inspection of the core shows that the specimen is a solid piece of calcareous algae of a type that normally contains 16+ per cent $MgCO_3$ in solid solution.

Random distribution of dolomitized limestones among atolls with respect to discrete time planes indicates a lack of regional oceanographic control over diagenesis in the material studied. Unique vertical distribution of dolomite in each atoll suggests local geologic control. The distribution of dolomitized zones beneath Funafuti and Kita-Daito-Jima eliminates any direct relationship between deep, long-term burial and intensity of dolomitization.

ORIGINAL RADIOGENIC LEAD IN Pb-U DATING

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The calculated lead-uranium age differs from the lead-lead ages obtained on specimens of most uranium ores and on many uranium-bearing minerals. For fresh unaltered uranium ores the Pb^{206}/U^{238} ages are somewhat less than the Pb^{207}/U^{235} ages, whereas Pb^{207}/Pb^{206} ages are significantly greater than either of the lead-uranium ages. This discordant age pattern has been interpreted as evidence for either the loss of daughter products (*e.g.*, radon 222 or lead) from the uranium series. Multiple periods of uranium deposition have also been considered the cause.

This paper suggests that discordant ages for certain uranium ores might best be explained by the presence of radiogenic lead deposited with the uranium. This original radiogenic lead was apparently formed by the radioactive decay of the uranium in a pre-existing site. These same ore solutions also transported the original radiogenic lead.

Isotopic analysis of the lead from the galena and pyrite associated with the uranium ores from the Colorado Plateau and the Blind River districts shows that: (1) lead is substantially enriched in radiogenic Pb^{206} and Pb^{207} compared to common leads, and (2) the Pb^{207}/Pb^{206} ages of this radiogenic component are appreciably older than the Pb^{207}/Pb^{206} ages of the uranium ores or the enclosing rocks.

Polished sections of uranium ores used for the age determinations indicate that the specimens represent only one period of uranium deposition and that deposition of galena and pyrite usually

preceded or accompanied deposition of the uranium minerals. In two instances paragenetic relations suggest that deposition of the galena continued after deposition of the uranium minerals. Nevertheless, the Pb^{207}/Pb^{206} ages of the radiogenic lead in these galena specimens are greater than the Pb^{207}/Pb^{206} ages of the associated uranium ores.

If original radiogenic lead is the explanation for the discordant $Pb/U \ll Pb^{207}/Pb^{206}$ age sequence of the Colorado Plateau and Blind River ores, the Pb^{206}/U^{238} age is most nearly accurate. It is unlikely that a single geologic process will account for this sequence.

MINING HYDROLOGY

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The presence of ground water in mines and quarries often has been the limiting factor in their operation. To provide the basic hydrologic and geologic information needed to attack such problems the U. S. Geological Survey has begun a program of research in mining hydrology.

Although a general solution to all such problems is unknown, a systematic investigation of each critical area, using the many tools developed in recent years for quantitative ground-water problems, often will produce sufficient data to solve individual problems. Such an investigation has as its objective the determination of the extent, composition, and hydraulic characteristics of the water-bearing beds and the occurrence, distribution, movement, and quality of the water within these beds. Analysis of the data thus obtained, if sufficiently detailed, will produce the most efficient program of water control, use, drainage, or pollution abatement needed to permit operations to continue.

GROUND-WATER PROVINCES OF INDIA

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The present Republic of India includes an area of 1,220,464 square miles and a population of more than 320 million. Within the Republic there is great diversity in the climatic, physiographic, and geologic environments, and consequently in the ground-water provinces related to them. With respect to the occurrence of ground water, India can be divided into 10 provinces, in three major regons: (1) the Peninsular region, (2) the Ganges-Brahmaputra region, and (3) the Himalayan region.

The Peninsular region contains six ground-water provinces. Precambrian igneous, metamorphic, and indurated sedimentary rocks and late Tertiary volcanic rocks in three of these provinces yield many small supplies of water, which generally is of good quality, but locally is brackish or salty. Cretaceous water-bearing sandstones in another province are moderately productive and in places are developed for large water supplies. Late Tertiary and Quaternary water-bearing sands and gravels in two of the provinces sustain many small water supplies and several large water supplies—particularly in the coastal areas of southern India.

The Ganges-Brahmaputra region includes two ground-water provinces in which many thousand small water supplies and several thousand large supplies are obtained from water-bearing sands and gravels in late Tertiary and Quaternary alluvium. These two provinces constitute a vast ground-water reservoir, the most productive in India. The Himalayan region is considered as a single province, in which ground water occurs in a series of narrow valleys filled with moderately to highly permeable Quaternary alluvium. These alluvial fills transmit large quantities of water to the ground-water reservoirs in the Ganges-Brahmaputra region.

SKITCHEWAUG NAPPE, A MAJOR RECUMBENT FOLD IN THE AREA NEAR CLAREMONT, NEW HAMPSHIRE

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Detailed mapping in the area near Claremont, New Hampshire, and Springfield, Vermont, has shown the existence of a recumbent fold with a maximum horizontal displacement of at least 10

miles. The upper limb has moved west-northwest relative to the lower. Rocks of the Partridge (?), Clough, Fitch, and Littleton formations are involved. Cross-bedding and the distribution of quartz conglomerate in the quartzites of the Clough formation show that the above order is that of deposition. Each formation appears in the biotite, garnet, staurolite, and sillimanite zones of regional metamorphism. Recognizable fossils have been found at eight localities in the upper part of the Clough formation, notably on Skitchewaug Mountain east of Springfield, Vermont (garnet zone), and on Croydon Mountain northwest of Newport, New Hampshire (staurolite and sillimanite zones). Preliminary study suggests that the fossils are Silurian or early Devonian. The least-deformed fossils are found either at the junction of the upper and inverted limbs of the nappe or in the upper limb close to that junction. Pebbles in the conglomerates are also less deformed in the axial regions of the nappe than on the limbs. The formation of the nappe is believed to be related to the emplacement of the Mt. Clough pluton. Later folds trending north-south have deformed the axial plane of the nappe in the vicinity of Skitchewaug Mountain.

URANIUM AND THORIUM DATING

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Two aspects to be considered in the application of the uranium-lead and thorium-lead systems to age determination are (1) which minerals give reliable (concordant) ages, and (2) what can be learned from those that give discordant ages. Several laboratories have found that uraninites from pegmatites generally give concordant uranium-lead ages. Zircon from pegmatites may serve as well. Other minerals such as monazite and microlite have frequently given discordant ages. Much work has been done to test the suitability of zircon for determining the ages of granites and syenites. These results indicate that only partial success has been obtained by this method. When the isotopic lead ages of a zircon are discordant, additional information from other minerals is required to ascertain the age of a granite with any high degree of certainty.

Understanding of the causes of discordant ages is still in an elementary stage of development. Acid-washing studies on samples with isotopically determined ages have demonstrated that inhomogeneities of uranium and thorium and their respective lead daughters exist in samples that have discordant ages. For example, a mineral with good uranium-lead ages and a low thorium-lead age will give an excess of thorium and radiogenic Pb^{208} compared to uranium and Pb^{206} and Pb^{207} in the acid wash. A mineral with high uranium-lead ages will give an excess of uranium and radiogenic Pb^{206} and Pb^{207} compared to thorium and radiogenic Pb^{208} in the acid wash. Minerals with concordant ages do not exhibit this tendency. These results suggest that transfer of lead daughters with the uranium or thorium parent from a mineral is the cause of many age discordances.

If losses of parent and daughter are taken to be the cause of discordant ages, a theoretical treatment may be used in some cases to obtain the age and the time at which losses took place by using groups of minerals from a given geological unit that give discordant ages.

SIGNIFICANCE OF TRACE ELEMENTS IN CARBONATE SEDIMENTS

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The sources of trace elements in carbonate sediments can be subdivided into various broad groups: (1) those deposited as minor constituents of calcium-carbonate–depositing organisms (such as Mg and Sr), (2) those related to the abundance of tests composed of some compound other than calcium carbonate such as celestite ($SrSO_4$), (3) those related to organic compounds trapped in the sediments (such as Ni, Cu, Mg), and (4) those related to the silicate contribution to the carbonate sediment.

Using the cases of a eupelagic deep-sea core, Bahamas sedimentation, and the make-up of the Florena (calcareous) shale (Permian), one can establish the usefulness of exploring the variations in these trace components in resolving problems in paleoecology and sedimentation history of a particular geologic sequence.

GROUND-WATER PROBLEMS IN NEW YORK AND NEW ENGLAND

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Some ground-water problems in New York and New England involve only a determination of the occurrence and quality of water in geologic formations and estimates of the productivity of wells. Other problems, such as sea-water encroachment in Long Island, involve complex problems, chiefly hydraulics of ground-water movement.

Increasingly, the problems involve the interrelationship between ground water and surface water, as in the following: (1) estimates of how changes in stream regimen affect ground-water conditions; (2) relative practicability of developing surface water or ground water for particular needs; and (3) measurement of surface discharge and separation of the hydrograph into direct-runoff and base-flow portions, to indicate amounts of ground water available.

An example of the first type is in the Ipswich River basin in Massachusetts, where investigations are related in part to indicating the possible effect of an artificial lowering of the river stage on near-by municipal well-water supplies.

An example of the second type is in the Blackstone River valley, Rhode Island. The problem is whether, for the city of Woonsocket and for industries, it is more practical to obtain additional water downstream from ground water or from surface reservoirs upstream.

An example of the third type is in the Pawcatuck River basin, Rhode Island, where a quantitative estimate is needed of the ground water available to supply a proposed industrial park. Location of prod[illegible]uifers can be based on ground-water studies alone, but estimation of the amount available [illegible] measuring river outflow and estimating evapotranspiration losses from swamps and lakes.

CARBONATE REPLACEMENT OF QUARTZ AND FELDSPAR AS A SOURCE OF SILICA IN SILICIFIED SEDIMENTS

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Petrographic studies indicate that silica released by carbonate replacement of detrital silicate grains may be the source of secondary silica in many silicified sediments. The studies indicate that partial to complete replacement of detrital quartz and feldspar grains is common in rocks associated with some silicified sediments, and that the volume of silica released by the replacement is adequate to supply the amount needed.

Replacement of detrital silicates and subsequent silicification possibly result from changes in pH of interstitial water. The time of [illegible]placement and silicification varies depending on local conditions. The higher permeability of unco[illegible]solidated sediments favors either syngenetic or diagenetic origin, but, with ground water as the agent for solution and transportation, the process could occur at any stage in the history of a sediment so long as diffusion can take place.

POTASSIUM-ARGON METHOD

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During the past 3 years the potassium-argon method has been critically evaluated. Retention of radiogenic argon by mica is nearly complete, while feldspars usually have lost significant quantities of argon. The problem of the decay constants, particularly the specific gamma activity, has been satisfactorily resolved as a result of improved counting experiments. As a consequence of these developments it is now possible to date a sample of mica with an error of less than 10 per cent, of the measured age, except for a few cases where some loss of argon seems to have occurred. Rather less reliable dating may be possible with feldspars if a correction is applied for loss of argon.

Similar progress has been made in rubidium-strontium dating, and it is now possible to measure

two independently reliable ages on the same sample of mica. This gives a check on the stability of the particular mineral sample used. The agreement of the K-A and Rb-Sr ages is suggested as a good criterion for acceptance of the absolute age of a sample of mica.

Application of this criterion will be illustrated by new measurements of the age of various Precambrian rocks.

DEVONIAN SECTION AT BOWMANSTOWN, PENNSYLVANIA

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Along the recently constructed north-south Turnpike crossing southeastern Carbon County, Pennsylvania, extensive cuts through ridges expose Devonian strata. The beds strike about east-west. At the south end of a section west of Bowmanstown, the oldest stand vertical. The dip of later beds, northward, flattens to nearly horizontal. An almost complete sequence is exposed from the Lower Devonian New Scotland formation into the Catskill continental red beds. Not only were the formations completely excavated, but their contacts were cleared. Most thicknesses were measured directly. The section is strategically located because it shows relationships between others east and west and illustrates facies changes along the strike.

STRUCTURAL ELEMENTS OF THE NORTHEASTERN APPALACHIANS

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Appalachian structures of central and east-central Pennsylvania include elements assigned to three epochs of folding—Taconic structures, dated in the late Ordovician; Acadian structures dated in the late Devonian; and folds of the terminal Paleozoic orogeny. Folds of the two older patterns can be traced northeastward from Susquehanna River through northwestern New Jersey and southeastern New York to Kingston on the Hudson and thence northward along the Hudson Valley toward Lake Champlain.

The strike of the youngest Paleozoic folds does not follow this familiar pattern; instead, folds assigned to the so-called "Appalachian Revolution" extend generally east from the Susquehanna to the Hudson, crossing Delaware River between Hancock and Port Jervis, New York, and passing across the high Catskill plateau. The trend of these late folds is essentially east-west where they cross the "little" folded mountains of the familiar Catskill-Kingston region; these small folds are entirely of Acadian age.

In following this easterly trend, the terminal Paleozoic folds converge toward and cross structural patterns produced by the Taconic and Acadian orogenies and are themselves interrupted by the Lackawanna syncline or northern anthracite basin. It is believed that the strong northeast trend of the Lackawanna basin has Triassic dating; that the west border of this unusual structure is controlled by Triassic faulting; and that many matters previously regarded as arising from Paleozoic deformation are better assigned to the Triassic.

It is suggested that the Green Pond syncline of New Jersey as well as the dominant course of Kittatinny Mountain from Delaware Watergap northeastward are both determined by Acadian rather than "Appalachian" folding.

STRATIGRAPHY AND STRUCTURE OF THE NORTH END OF THE TACONIC RANGE, VERMONT

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A revised stratigraphic sequence is proposed for the north end of the slate belt. This section, the tops-and-bottoms sense of which was confirmed by primary structures, consists of three major units: a basal purple and green chloritoid slate (the Biddie Knob formation); an intermediate Bull forma-

tion consisting principally of purple and green slates but including distinct and mappable units of graywacke, arkose, quartzite, and limestone conglomerate; and a black slate formation (the Hooker) with subsidiary dolomite, limestone, and quartzite beds. The Bomoseen grit appears to be a lithofacies which in the eastern portion of the area is entirely within the Bull formation, but thickens westward at the expense of the underlying units. Fossils in the Bull and Hooker formations indicate that the bulk of the section is early Cambrian in age although some Ordovician slate may exist at the top.

Tracing of the lithologic units revealed a complex map pattern within the framework of the south-plunging Middlebury synclinorium. The dominant structural motif is horseshoe-shaped folds best developed along the axis of the synclinorium. In this same area, thrusting and recumbent folding also prevail; toward the west the folds become more open and overturn simply to the west.

The Ordovician limestones adjacent to the slate belt have been similarly deformed. At least part of the Whipple marble is early Canadian in age and constitutes the remains of a nappe. The east end of the Sudbury thrust also disappears under the Taconic sequence and tectonically seems to be an integral part of it.

The overall structure can be interpreted in numerous ways. If the slates were autochthonous, the structure must be some sort of a mushroom fold. However, if the rocks were allochthonous, then it may be either a folded simple thrust or a gigantic recumbent fold refolded after its emplacement. Unfortunately, considerable difficulties attend each explanation. Their relative merits are presented and discussed.

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